DRIVER INFORMATION SYSTEMS FOR HIGHWAY - RAILWAY GRADE CROSSINGS

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BY

T. URBANIK

JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Final Report

DRIVER INFORMATION SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

July 7, 1971

File No.: 8-5-12

Project No.: C-36-59L

The attached Final Report "Driver Information Systems for Highway-Railway Grade Crossings" is submitted as fulfillment of the objectives of the Plan of Study titled "An Evaluation of Safety at Highway-Railway Grade Crossings" approved by the Advisory Board on May 27, 1970. The report has been authored and the research performed by Mr. Thomas Urbanik, II, Graduate Assistant in Research on our staff, under the direction of Professor K. W. Heathington.

Four objectives of the research were met and the results reported. Driver attitude concerning the hazard at railroad grade crossings, citizen appraisal of priorities for improving grade crossing safety, driver evaluation of possible warning systems for crossings, and the development of the general design of a proposed new advance warning system are presented.

The report is presented to the Board for action. Comments on the report would be appreciated and any application of the results by the ISHC or other agencies would be especially appreciated.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

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Final Report

DRIVER INFORMATION SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

by

Thomas Urbanik, II
Graduate Assistant in Research

Joint Highway Research Project

File: 8-5-12

Project: C-36-59L

Purdue University
Lafayette, Indiana
July 7, 1971

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This research was aided by many persons, but it is impossible to give them all the thanks they deserve in this short space. Therefore, the author first wishes to express his appreciation to those who gave assistance to this project, but are not specifically acknowledged.

This research was the result of the guidance of major professor Dr. Kenneth W. Heathington. Assistance was also provided by Professor Harold L. Michael, Associate Director of the Joint Highway Research Project, and Professor I. W. Burr of the Mathematics Department.

My wife Cynthia, who coded data, proofread all material, and provided continual assistance and support throughout this entire project, deserves much credit for the completion of this project.

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ABSTRACT

Urbanik, Thomas, II. M.S.C.E., Purdue University, June 1971. Driver Information Systems for Highway-Railway Grade Crossings. Major Professor: Dr. Kenneth W. Heathington.

The reduction in accidents at highway-railway grade crossings is a desirable objective. To fulfill this objective past research was examined and a new direction was taken relative to improving safety at highway-railway grade crossings. This new direction was to improve the warning systems at individual crossings rather than an examination of priorities for improvement of railroad crossings or an examination of the effectiveness of present warning systems.

The research utilizes an attitudinal survey in order to meet four broad objectives. These objectives were an evaluation of driver attitudes concerning the hazards at railroad grade crossings, an evaluation of priorities for improving safety at railroad grade crossings, an evaluation of warning systems for railroad grade crossings, and the development of a typical design for a new advance warning system.

The research indicates that the respondents considered railroad grade crossings more hazardous than several other highway hazards. However, all hazards were, at most, only considered moderately hazardous by the respondents. The improvement of safety at railroad grade crossings was given high priority by the respondents. An

overhead changeable message sign was the most preferred method of warning at railroad grade crossings. It was concluded that a field installation is desirable.

CHAPTER I. INTRODUCTION

Highway-railway grade crossings constitute a hazard to the highway traveler. In the United States in 1969 there were 3,774 grade crossing accidents involving pedestrians, automobiles, trucks, buses, motorcycles, and other miscellaneous vehicles (11). These grade crossing accidents resulted in 1,490 fatalities and 3,669 personal injuries. Railroad grade crossings account for only 0.1 percent of the total accidents in the United States (26). However, these accidents are very severe. The severity is indicated by the fact that railroad crossings account for an average of 2.5 percent of the total automobile accident fatalities in the United States (26).

Of the 3,774 crossing accidents in 1969, 3,572 involved collisions between railroad movements and motor vehicles. These 3,572 accidents resulted in 1,381 deaths and 3,578 injuries. In two-thirds of these 3,572 accidents, trains struck motor vehicles. The remaining one-third of these accidents involved motor vehicles striking the sides of trains (11).

Protected crossings, those having gates, trainmen, watchmen, or audible and/or visual signals, account for approximately 22 percent of the 211,993 highway railway grade crossings in the United States. Protected crossings, however, account for approximately 42 percent of the 3,572 motor vehicle accidents at grade crossings (11). Although

other factors such as train and motor vehicle volumes are involved, it would appear that present protective devices are less effective than would be desirable.

The grade crossing problem is even more serious in Indiana. In the period 1965 to 1968, railroad grade crossings in Indiana were 0.4 percent (0.1 for U.S.) of the total accidents, and were 6.0 percent (2.5 for U.S.) of the total fatalities (11). Indiana consistently has a large number of railroad crossing accidents.

It is worthwhile to look at rural grade crossing accidents. The higher operating speeds at rural crossings are reflected in accident severity. During the period 1966 to 1968, rural Indiana railroad crossing accidents averaged 31 percent of the total grade crossing accidents. However, fatalities average 56 percent of the total fatalities (19). Thus it would seem that rural grade crossing accidents, at least in Indiana, are more severe than urban grade crossing accidents.

It should also be noted that although all grade crossings average one traffic accident every 22 years, some grade crossings have a number of accidents every year. For example, one crossing on U.S. 52 in Indiana has had at least one fatality and four total accidents each of the last three years (19). These accidents occur despite automatic protection in the form of flashing lights. It becomes evident that present protection systems, short of complete grade separation, are at best only partially successful.

Previous Research

The focus in the past concerning railroad grade crossing problems has been primarily on hazard index formulas and accident prediction equations. The purpose of these formulas and equations has been to determine the priorities for the improvement of protection at specific grade crossings. The reason that priorities are needed is that there are numerous grade crossings that could be improved, the cost of improvement such as flashing lights and gates is large, and the amount of money available is limited.

Indications are that current techniques for computing the relative hazard index are reliable. Bezkovavainy (6) applied eleven hazard index formulas to 180 railroad grade crossings and concluded that each formula gave basically the same relative priority for improvement of the crossings. In addition, Schultz (23) has developed models to predict the relative hazard for rural grade crossings in Indiana and Berg (5) developed similar models for urban areas.

Other significant research can be categorized as before and after studies. Voorhees (26) concluded that the results of numerous before and after studies indicate general agreement concerning the relative effectiveness of present protection devices in reducing the hazard at a railroad grade crossing. Automatic gates are considered to be the most effective protection followed in order by flashing lights, wigwags, and crossbucks.

Although complete grade separation is one solution to reducing grade crossing accidents, grade separations require substantial resources. There is a large cost differential between a grade

separation and present automatic protection systems. Flashing lights with gates cost approximately $25,000 for installation. The cost of a grade separation ranges from $300,000 for a two-lane rural location to more than $800,000 for a four-lane urban location (26). Therefore situations exist that could justify more effective protection at a cost less than that of complete grade separation.

Development of Objectives

It would seem that future research efforts might be more appropriately directed toward improving safety measures at individual crossings, especially in rural areas. An area that has received little attention in the past is that of basic information supplied to the motorist. The standard flashing lights are located adjacent to the roadway and tracks. Besides constituting a hazard because of its location, its adequacy for providing sufficient advance warning is questionable. Studies in human factors (3) also indicate that the distinctive round shape of the present advanced warning sign cannot be discerned before the message.

New technology in electronics permits better information to be furnished to the driver. Signs that can display several different messages outside the vehicle are available and it is possible to provide audible signals or messages and/or visual signals or messages within the vehicle.

Considering the desirability of reducing accidents at railroad grade crossings and the capabilities of modern electronics, four broad objectives were developed for this research. The objectives of this research were:

1. evaluate driver attitudes concerning the grade crossing hazard,

2. evaluate driver priorities for improving the safety at grade crossings relative to other highway improvements,

3. propose and evaluate new advance warning systems for railroad grade crossings, and

4. develop a typical design for a new advance warning system for railroad grade crossing protection.

To meet these objectives, 259 drivers were surveyed. Based on the results of the driver survey, a specific system for railroad grade crossing protection was designed.

Areas of Research

In Chapter II a review of literature concerning driver information systems is made. The purpose of this review is to provide the background to this study and to show the capabilities of modern driver communication systems. Those aspects of previous research that are pertinent to an advance warning system at railroad grade crossings are indicated.

Chapter III reports on the general details of the design of the research. The design of the questionnaire and its pretesting are discussed. The method of selecting the sample along with the social and driving characteristics of the respondents are reported.

Chapters IV, V, VI, and VII cover the analysis of the questionnaire. The evaluation includes driver attitudes concerning the hazard at grade crossings, an evaluation of driver priorities for grade crossing improvement, an evaluation of alternative advance warning

systems, and an evaluation of the specific displays to be used.

Finally, Chapter VIII details the design of an advance warning system for railroad grade crossings in Indiana. Included in the design are a detailing of the equipment, an estimation of costs, and an estimation of possible benefits.

This research explores new concepts in the design of a driver information system for highway railway grade crossings. The final test of this research is the field evaluation of the concepts developed and tested.

CHAPTER II. RELATED RESEARCH

As the task of driving has become more complex, interest has increased in driver information systems. Basic static signs (i.e., signs that always display the same message) are not desirable in many driving situations. Some agencies have begun using changeable message signs (18). Changeable message signs are signs that can display two or more alternative legends. Examples include variable speed signs, warning signs for bad weather or accidents, and signs used to give freeway conditions or information on alternate routes. As the electronic capabilities continue to be developed and perfected, these signs should find increasing usage in many different situations. Review of previous research into driver information systems utilizing advanced electronic capabilities has provided the basis of this research concerning an advance warning system for railroad grade crossings.

Changeable Message Signs

The Chicago Area Expressway Surveillance Project has conducted research on the provision of real time information on the operation of the westbound Eisenhower Expressway and its entrance ramps (18). Electronic signs are operated in conjunction with expressway ramp control provided by the Chicago Area Expressway Surveillance Project. Using electronic surveillance of the number and location of vehicles on the expressway, the number of vehicles entering the expressway at each

entrance ramp is controlled in order to optimize the performance of the expressway. In conjunction with the ramp metering, changeable electronic signs are used to alert drivers to the traffic conditions at the various ramps and merge areas. These signs, through color coding, help the driver to determine whether he should use the expressway or the arterial street system for his trip.

In-Car Devices for Driver Information

There have been experiments using radio transmissions to provide drivers information on traffic conditions (7, 8, 12). The type of radio transmission most applicable to this research is based on the induction loop principle. The induction loop principle simply uses a buried cable near the roadway as a means of transmitting a radio signal over short distances. This short range results in a minimum of interference with regular radio stations. The induction loop broadcasts can be received on regular car radios or special receivers.

A radio communications system has been developed by General Motors (12). The system is called DAIR--Driver Aid, Information and Routing. This particular system has two-way communication while other systems use a simpler one-way communication. Information can be transmitted from a central communications center or from roadside transmitters. The DAIR system is very sophisticated compared to other systems in that many options are available. The DAIR system informs the driver of speed and traffic signs, allows him to summon help in an emergency, and provides automatic routing for his trip.

A subsystem of the DAIR system is the simple roadside communication link. Using an induction loop, preprogrammed messages are given

concerning traffic conditions, regulatory signs, and warning signs. This subsystem is the basis of most other radio communication systems. The Georgia Institute of Technology tested such a system along a ten-mile section of the Kentucky Turnpike (7, 8). Acceptance by the user of the system was good.

Another type of in-car device uses visual messages. These devices also use short-range roadside communications. An Experimental Route Guidance System (24) called ERGS was developed by General Motors for the Federal Highway Administration. This system utilizes a dashboard visual display to give routing directions to a driver for a pre-specified destination. When the driver enters his vehicle, he dials the code number of his destination into his ERGS console. As the driver approaches an intersection, the dashboard display gives the necessary information concerning which lane to use and when and where to turn. Since the system is destination rather than route oriented, driver errors are easily corrected. If a driver misses a turn, he is simply given directions on how to reach his destination from the next intersection.

An improvement over the dashboard display is the head-up display (4). The head-up display is a technique developed as a pilot landing aid. This concept utilizes a virtual image superimposed upon the real world. That is, it is possible to display words and/or symbols such that a driver can read the message and still be watching the road. This system was designed as an extension of the ERGS system. It has the advantage of not distracting the driver or blocking his vision. It also has a set of 16 basic directional symbols developed by the Federal Highway Administration for route guidance.

Real Time Information Systems

Several recent projects have been concerned with real time information for drivers. Heathington (14) used an attitudinal survey to evaluate driver attitudes towards a Freeway Driver Information System (FDIS). The research included an evaluation of the willingness of Chicago area drivers to pay for an information system on Chicago expressways, an evaluation of the likelihood of diversion to alternative routes when given specific information on freeway conditions, and an evaluation of the specific messages to be used for three levels of congestion. The transportation improvement considered most important by the Chicago drivers surveyed was the improvement of the riding surface on expressways. More important, the provision of electronic signs giving information on traffic conditions rated second. This indicates the importance that Chicago drivers placed on real time information. With regards to the specific sign messages on the FDIS, the respondents indicated a preference for traffic information over non-traffic information at all levels of congestion. Therefore, even if no congestion exists, the drivers desired to be told that no congestion exists rather than be told nothing.

Hoff (17) looked at alternative methods of communicating with drivers. The purpose of his research was to look at different traffic information techniques which might be used to divert drivers around congested areas of the highway system. A questionnaire was developed to determine the preference of drivers for six alternative methods of communication. The ordered preference of Chicago drivers for methods of receiving information concerning freeway conditions was as follows:

1. changeable message sign,
2. symbolic map with arrows and streets,
3. symbolic map with arrows,
4. commercial radio,
5. roadside radio, and
6. experience.

Dudek and Jones (10) also evaluated real time visual displays for urban freeways. This research was directed toward the development of functional requirements for a real time freeway communication system for urban areas. The researchers felt that it was essential that the motoring public play a major role in establishing the functional requirements of the system, since the system must fulfill their needs. Their research was directed toward evaluating driver attitudes concerning the need for real time information, the potential use and response to real time information, driver preferences for mode of communication, the type of information desired, the priorities for the location of information, and driver comprehension of and preferences for visual displays. This work was patterned after the work of Heathington (14) and Hoff (17). The surveyed Texas drivers were given three alternatives for real time information. The three alternatives were (1) real time information, (2) additional guide signs, and (3) other (to be filled in by the respondent). The results indicate a preference for real time information over additional guide signs. Only a small number of respondents filled in an alternative type of system. Their findings also indicated that Texas drivers preferred simple descriptive and color-coded displays over more complicated displays involving diagrams.

Dudek and Cummings (9) also evaluated alternative information systems. The main objective of this study was to investigate the application of commercial radio to freeway communication. As a part of this study alternative modes of communicating with drivers were evaluated using an attitudinal questionnaire. This survey of Texas drivers indicated the following order of preference for urban freeway information:

1. radio,
2. signs,
3. television, and
4. telephone.

They concluded, however, that no appreciable differences existed between the radio and sign modes. For all practical purposes, the radio and sign modes of furnishing freeway information were considered equal.

Summary

This previous research concerning driver information systems indicates that improved driver communication is desired by drivers. A logical extension of this previous research would be the application of the technology developed to other traffic situations. One extension of this previous research is the evaluation of advanced warning systems for railroad grade crossing protection. The ERGS (24) type system could be used to give drivers visual information inside vehicles concerning the hazard at railroad crossings and other highway hazards. A roadside radio communication system (12) could also be used to provide audio warning messages at railroad crossings and other highway hazards.

Finally, a changeable message advance warning sign could be used to provide advance warning at highway-railway grade crossings.

CHAPTER III. DESIGN OF RESEARCH

The research method selected for evaluation of specific concepts of advance warning systems for highway-railway grade crossings was an attitudinal survey of drivers. This is not the only method of research that could have been used for the evaluation. The more commonly used method in traffic engineering involves field testing. One can construct a system and then evaluate various aspects through alteration of the system over a period of time. This is an expensive procedure and often does not permit sufficient variation in system design for proper evaluation.

Using an attitudinal survey, one can evaluate several alternatives more quickly and at a much lower cost than through actual field construction. This type of attitudinal research is not intended to replace final field evaluation of any system. The purpose of the attitudinal research is simply to aid in the planning and design of the best possible warning system as quickly, as efficiently, and as economically as possible.

In order to meet the objectives of this research, two psychological scaling techniques (13) were selected for obtaining driver attitudes. The method of paired comparisons was selected for its ability to establish a relative ranking of several highway hazards, alternative methods of warning, and alternative messages for warning

systems. A rating scale was also used to establish an absolute scale for several highway hazards, alternative methods of warning, alternative messages for warning systems, and for several alternative highway improvements. These two techniques have been used extensively in the area of transportation research by General Motors (2), Heathington (14), Hoff (17), and MacGillivray (20). The theoretical basis of these psychological scaling techniques will not be discussed in detail, but the interested reader is referred to a brief explanation of these techniques in Appendix B and to the works listed in the bibliography.

Questionnaire Design

The first objective of this research was to evaluate driver attitudes concerning the hazards at railroad grade crossings. It was decided that driver attitudes concerning grade crossings could best be evaluated relative to other similar highway hazards. Five other hazards were selected for evaluation along with grade crossings. Four of these hazards were different types of intersections and the fifth was a highway curve. The differences between intersections were in types of control. A signalized, a stop controlled, a yield controlled, and an uncontrolled (crossroad) intersection were the types of intersections used in the survey.

Questions A and B of the attitudinal survey (see Appendix A) concerned the evaluation of the six highway hazards. Question A used the method of paired comparisons to provide a relative ranking of the hazards. Question B used a rating scale to determine an absolute scale for the six highway hazards.

The second objective of this research was to evaluate the economic priorities for improving railroad grade crossings relative to eight other highway improvements of approximately the same cost. In Question C of the attitudinal survey, the 259 respondents evaluated each of the nine alternatives using a rating scale.

The third objective of this research was to evaluate new advance warning systems for highway-railway grade crossings. The first phase of this part of the research was to arbitrarily select and evaluate suitable advance warning systems. The three new systems were a changeable message advance warning sign, an in-car visual display, and an in-car audio message. The changeable message sign was an overhead sign that would have different displays depending on the conditions. The in-car devices were patterned after the ERGS (24) and DAIR systems (12). In addition, two present warning systems were included in the analysis to provide a comparison between present and proposed systems. The two present systems were the active type of protection represented by automatic flashing lights and the passive type warning sign. Questions D and E of the attitudinal survey were used to evaluate the relative and absolute acceptability of the five methods of warning. Question D used the method of paired comparisons to evaluate the relative acceptability and Question E used a rating scale to evaluate the absolute acceptability of the warning systems.

The second phase of the analysis of advance warning systems for highway-railway grade crossings concerned the displays that could be used to warn drivers. Five alternative displays were evaluated for each of two different situations. The first condition occurs when a

train is near a crossing and a driver needs to stop. The other condition occurs when there is no train near the crossing. Questions F, G, H, and I of the attitudinal survey were used to evaluate displays for both conditions. Questions F and H used the method of paired comparisons to evaluate the relative acceptability of the alternative displays for each condition. Questions G and I used a rating scale to determine the absolute acceptability of alternative displays.

The final question of the attitudinal survey was used to determine the social and driving characteristics of the respondents. Characteristics that were asked included sex, age, education, and miles driven per year.

The final objective of this research could not be met until the first three objectives were completed. The results of the attitudinal survey were used to design and evaluate the cost of an advance warning system for highway-railway grade crossings at selected locations in Indiana.

The Pretest

The actual design and pretesting of a questionnaire is one of the more crucial phases in attitudinal surveys. Too often a poorly designed survey instrument comes to light only after the data has been collected and the analysis begun. Pretesting is a means to locate problems in questionnaire design prior to data collection. Regardless of the experience of the person designing the questionnaire, improvements will usually be necessary as a result of the pretest.

The first pretest of this attitudinal survey was conducted on twelve graduate students in a Systems Analysis class at Purdue

University. The persons involved represented several disciplines. The students did not know that the questionnaire was being pretested. Two changes were made as a result of the critical evaluation of the respondents after completion of the questionnaire.

After the necessary changes were made, a second pretest was conducted at the Purdue Student Chapter of the Institute of Traffic Engineers. The revision was administered to ten members unfamiliar with the study. The respondents did not know the questionnaire was being pretested. This presentation proceeded without any problems. It was concluded that no further changes in the questionnaire were necessary or desirable.

The Participants

The next phase of the research was data collection. Ideally, a systematic random sample would be drawn from the population of Indiana drivers. An alternative approach was necessary due to resource limitations. The method of data collection chosen was to administer the questionnaire to groups from various segments of the driving population.

The groups chosen for administration of the questionnaire were:

1. The Lions Club of Lafayette

2. Clerical employees of State Farm Insurance Company (non-automobile divisions)

3. The Lafayette Army Reserve Unit

4. A Purdue University undergraduate class

5. Central Catholic High School students (Lafayette)

6. Wainwright High School students (Tippecanoe County)

7. Southwestern High School students (Tippecanoe County)

Table 1 shows some characteristics of the 259 respondents. The important aspect to note is that a large range of social and driving characteristics are represented in the sample. Approximately 81 percent of the respondents were males and 19 percent were females. Approximately one-third of the respondents were under age 20, approximately one-third were age 20 to 29, and approximately one-third were over age 29. Respondents without a high school diploma represented approximately one-third of the total respondents, and high school and college graduates each represented approximately one-third of the total number of respondents. Approximately 50 percent of the respondents drove less than 10,000 miles per year and approximately 50 percent drove more than 10,000 miles per year. It can be seen that a wide range of social and driving characteristics are represented by the 259 respondents.

TABLE 1. CHARACTERISTICS OF PARTICIPANTS

PARTICIPANTS BY SEX

Sex	Number	Percent
Male	209	80.7
Female	50	19.3
	259	100.0

PARTICIPANTS BY AGE

Age	Number	Percent
Under 20	94	36.3
20-24	59	22.8
25-29	26	10.0
30-34	6	2.3
35-39	11	4.3
40-49	28	10.8
50-59	19	7.4
60-69	13	5.0
70 or more	3	1.1
	259	100.0

PARTICIPANTS BY EDUCATIONAL LEVEL

Education	Number	Percent
1-8 years of grade school	2	0.8
1-3 years of high school	86	33.2
Graduated from high school	32	12.4
1-2 years of college or trade-school	51	19.7
Graduated from college	47	18.1
Completed graduate degree	41	15.8
	259	100.0

TABLE 1, cont.

PARTICIPANTS BY MILES DRIVEN PER YEAR

Miles	Number	Percent
Under 5000	66	25.5
5000-7500	34	13.1
7500-10000	32	12.4
10000-12500	44	17.0
12500-15000	33	12.7
Over 15000	50	19.3
	259	100.0

PARTICIPANTS BY INCOME LEVEL

Income Level	Number	Percent
Under 2500	7	2.7
2500-5000	20	7.7
5000-7500	16	6.2
7500-10000	21	8.1
10000-12500	17	6.6
12500-15000	23	8.9
15000-17500	15	5.8
17500-20000	17	6.6
Over 20000	29	11.2
Not asked*	90	34.7
Refused	4	1.5
	259	100.0

*High school and college students not asked.

CHAPTER IV. AN ANALYSIS OF DRIVER ATTITUDES TOWARDS SEVERAL HIGHWAY HAZARDS

The first objective of this research was to evaluate driver attitudes concerning the hazard at highway-railway grade crossings. A survey of 259 drivers was made to determine attitudes on a relative scale and on an absolute scale. The relative scale will indicate how hazardous the drivers considered railroad grade crossings relative to several other hazards. The absolute scale will indicate whether the drivers considered railroad grade crossings and the other alternative hazards to be very hazardous, not very hazardous, or somewhere in between.

Six highway hazards were selected for analysis. The six highway hazards selected were:

1. a railroad grade crossing;
2. a signalized intersection;
3. a stop controlled intersection;
4. a yield controlled intersection;
5. an uncontrolled intersection (crossroad); and
6. a curve.

Five of the six hazards are intersections with various types of control. The railroad grade crossing is unique in that it is the intersection of two modes of transportation with vastly different operating

characteristics. One of the important differences in operating characteristics of highway-railway grade crossings is the inability of trains to stop in a short distance. Railroad trains require such large stopping distances that they are always given the right-of-way. Another difference is that a relatively small number of trains pass over a grade crossing each day. The advance warning sign for a railroad grade crossing is the same for crossings with automatic signals and for crossings marked only with signs.

A signalized intersection alternately assigns the right-of-way to each road or street. It also gives an identifiable yellow clearance interval which indicates that the right-of-way is changing. Unlike the railroad engineer, the defensive driver may give up his right-of-way to another driver.

A stop controlled intersection requires the driver to relinquish the right-of-way to cross street traffic. Typically, a major street is given a constant right-of-way in preference to the stop controlled minor street. A yield controlled intersection indicates the need to stop only when a vehicle is approaching on the cross street. Finally, a crossroad as presented in this research was a through road intersected by a high volume road. The crossroad sign would be erected only when sight distance was restricted on the through road.

The final hazard evaluated was a simple highway curve. The hazard as presented in this research was a curve without any advisory speed reduction. All six hazards in this research require advance warning signs for restricted sight distance. The advance warning sign for railroad grade crossings is required at virtually all crossings with the following exceptions:

1. at a minor siding or spur which is infrequently used and when in use is guarded by a member of the traincrew; and

2. at crossings in business districts which are fully protected and have physical conditions which make even partially effective display of the sign difficult.

Methods of Evaluation

The method selected to obtain the necessary driver attitudes was a structured questionnaire using psychological scaling techniques. Two psychological scaling techniques, the method of paired comparisons and a rating scale, were used to evaluate the respondents' attitudes toward each of the six hazards. The method of paired comparisons was used to establish relative ranking of the hazards. The rating scale was used to establish absolute importance of each hazard.

The method chosen to present these six stimuli to the 259 respondents was photographs of the standard advance warning sign (22). In order to present the hazards under realistic conditions, photographs were taken of the advance warning sign for each hazard properly mounted along a two-lane state highway. All signs were photographed at the same location, as shown in Figure 1, so that all possible effects of the highway scene would be the same for all hazards. The location was selected such that any hazard could exist just beyond the crest of a small hill.

It should also be noted that this portion of the research appeared first so that the results would not be affected by questions specifically concerned with railroad crossings. This added precaution

Railroad Crossing

Crossroad

Signal Ahead

Yield Ahead

Stop Ahead

Curve

FIGURE 1. PHOTOGRAPHS OF SIX HIGHWAY HAZARDS
AS VIEWED BY THE RESPONDENTS

was taken even though the respondents were never informed that the research was primarily concerned with railroad grade crossings.

A Relative Scaling for Six Highway Hazards

The paired comparison technique was used to evaluate the relative hazard of a railroad grade crossing, a signalized intersection, a stop controlled intersection, a yield controlled intersection, a crossroad, and a highway curve. Since the number of pairs necessary for the paired comparison analysis is $n(n-1)/2$, where n is the number of alternatives, fifteen pairs of hazards are required. Because of several possible sources of error, the pairs were presented in a different random order to each group of respondents. This randomization reduced the effect of persons who have a tendency to always pick the first (or second) response and to reduce the effect of becoming tired after seeing a large number of pairs of alternatives. That is to say, if a specific pair was given last to one group, it may have appeared first to another group.

Using two synchronized 35mm slide projectors, two slides of hazards were displayed side by side on two screens as illustrated in Figure 2. The hazard shown on the screen to the left was labeled A and the hazard on the screen to the right was labeled B. The first two slides shown were an example. Slide A was a truck crossing and slide B was a hill. The respondents were instructed to assume they were driving along a highway. If they thought a truck crossing was a more hazardous situation, then they were told to mark the letter A on their answer sheet as shown in Figure 3. If, on the other hand, they felt that the hill was a more hazardous situation, then they were told to

A B

FIGURE 2. AN EXAMPLE OF THE PAIRED COMPARISON PRESENTATION

Which sign warns of a more hazardous situation?

EXAMPLE SLIDE 1. A B

FIGURE 3. AN EXAMPLE OF THE PAIRED COMPARISON ANSWER FORM

mark the letter B on their answer sheet. In the event they felt both hazards were equally hazardous, then they were told arbitrarily select either A or B.

After the example was given and any questions answered, the fifteen pairs of hazards were shown. Each pair of slides were shown for 12 seconds followed by a three-second interval in which nothing was shown. This three-second interval indicated the end of the allotted time and allowed a period to mark the appropriate answer. Although the time allowed seems short, it was found during the pretest that this length of time was quite adequate.

The results of the paired comparison analysis of the six hazards for all 259 respondents are shown in Figure 4. The details of the calculations used to arrive at the scale values are shown in Appendix B. As seen from Figure 4, the railroad grade crossing was the most hazardous situation with a relative scale value of 0.59. The second most hazardous situation with a relative scale value of 0.53 was a crossroad. Third, with a scale value of 0.45, was a yield controlled intersection. Further down the scale with 0.29 scale value was the stop controlled intersection. This was the approximate mid-point of the scale. The last two hazards were nearly identical with the signalized intersection having a scale value of 0.05 and the highway curve having a scale value of 0.00. That is to say, drivers consider a signalized intersection about as hazardous as a curve.

Thurstone suggests that if the paired comparison assumptions are adequately met, then one should be able to work backwards from the scale values and recreate the originally observed proportions (24).

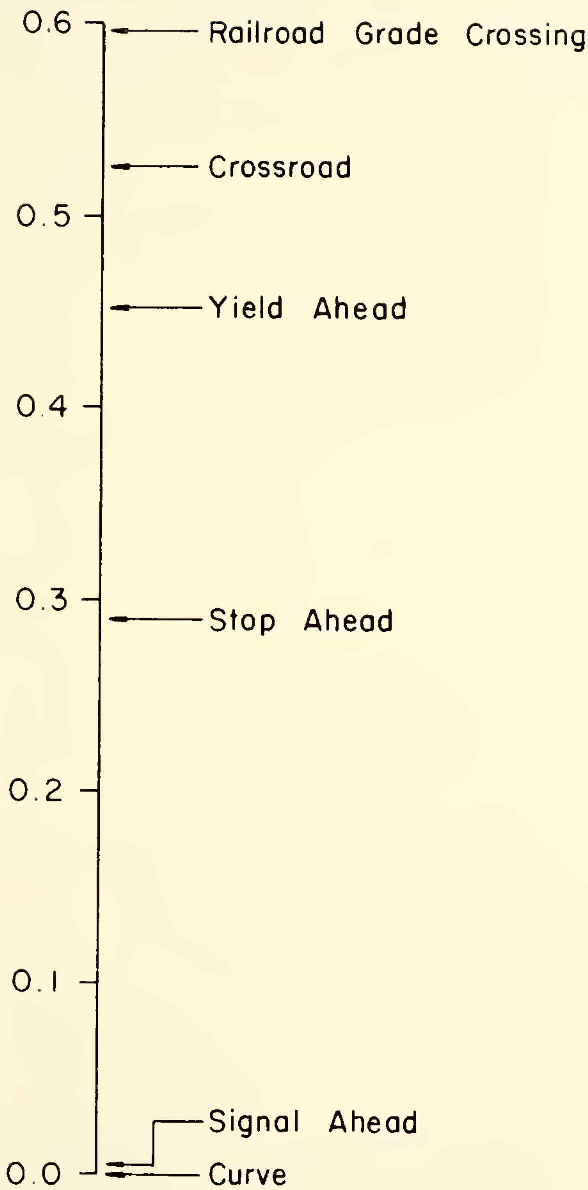


FIGURE 4. A RELATIVE SCALE FOR SIX HIGHWAY HAZARDS

Ideally, these calculated proportions would be identical to the observed proportions. Therefore, if a good fit of the observed data was made, a plot of the observed proportions (P'_{ij}) versus the calculated proportions (P''_{ij}) should approach a 45 degree straight line through the origin. The better the fit, the closer the data would approach a straight line. Figure 5 is a plot of the calculated versus the observed proportions for all respondents. The plot indicates a reasonably good fit of the model to the data.

Another indicator of the validity of the model is obtained by a least squares fit of the P'_{ij} versus P''_{ij} data points. The assumptions of a linear model are not necessarily met, but the slope, intercept, and simple correlation provides an indication of the validity of the paired comparison model. That is, the slope of the fitted line should be 1.00, the intercept should be 0.00, and the correlation 1.00 if the paired comparison model is a perfect fit of the observed data. For the plot shown in Figure 5, the slope is 0.93, the intercept is 0.04, and the correlation is 0.96. This indicates a reasonable fit of the data by the paired comparison model.

A Relative Scaling by Subgroups for Six Highway Hazards

In designing an advance warning system for highway-railway grade crossing, one finds it helpful to know if any subgroups of respondents have different attitudes concerning the hazards. If any major subgroups have different attitudes than the respondents as a whole, then any design would have to take the differences into account. Therefore, the sample was divided into four subgroups. The subgroups were sex, miles driven per year, education, and age. These four

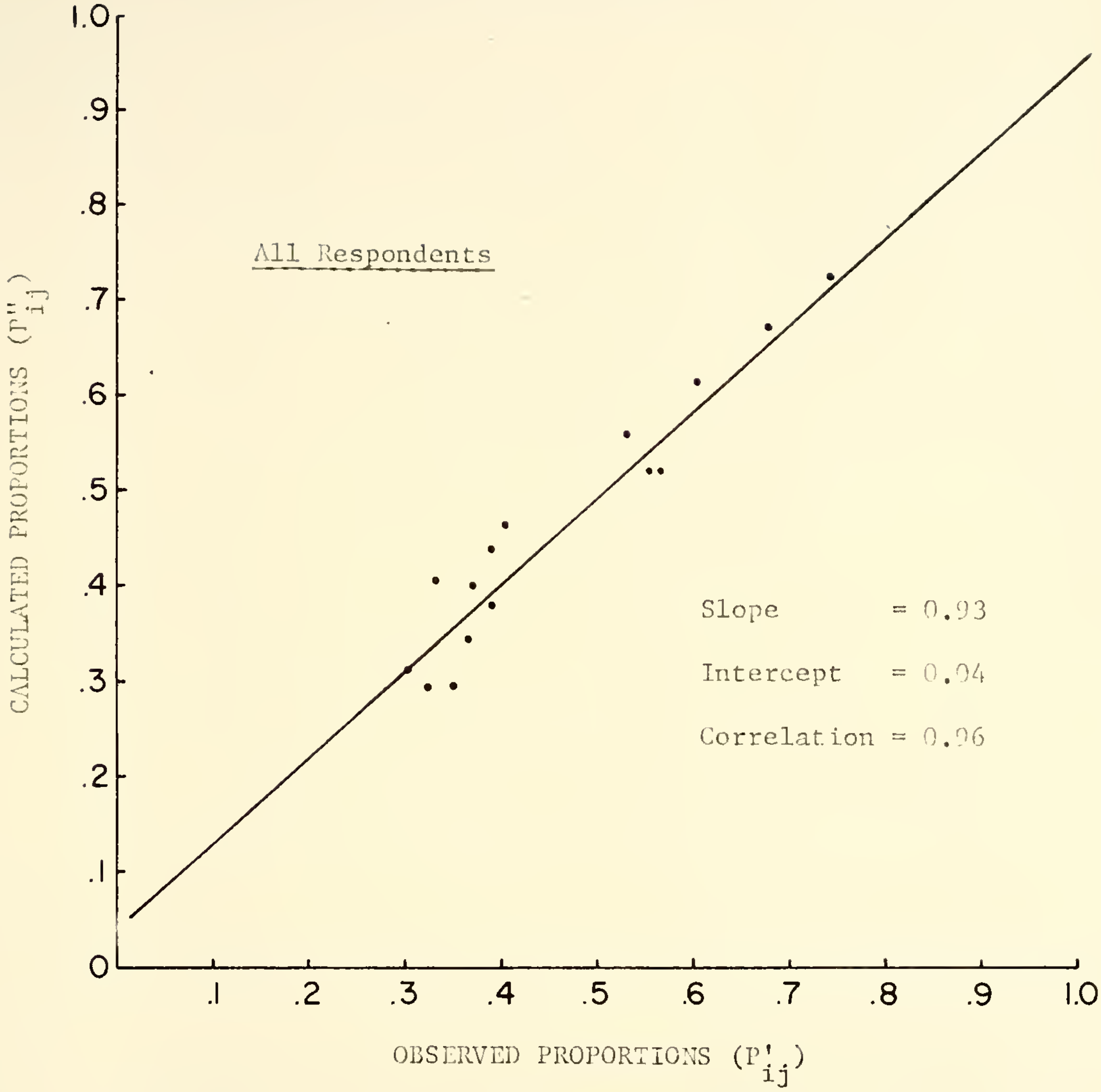
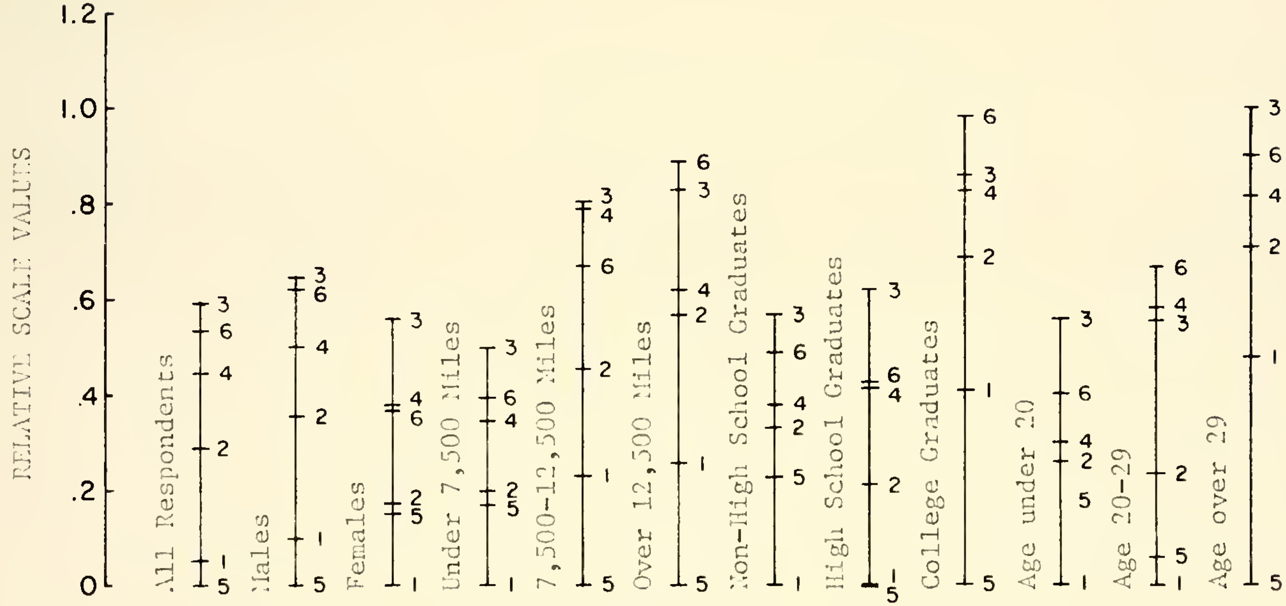


FIGURE 5. CALCULATED VERSUS OBSERVED PROPORTIONS FOR SIX HIGHWAY HAZARDS

subgroups were further divided into the following eleven categories for analysis:

1. respondents who were males;
2. respondents who were females;
3. respondents driving under 7,500 miles per year;
4. respondents driving 7,500-12,500 miles per year;
5. respondents driving over 12,500 miles per year;
6. respondents who had not graduated from high school;
7. respondents who had graduated from high school;
8. respondents who were college graduates;
9. respondents under 20 years of age;
10. respondents 20-29 years of age; and
11. respondents over 29 years of age.

Figure 6 shows the relative scale values for the eleven categories of subgroups. It can be seen that only very minor changes occur in the relative ranking among subgroups. Only three subgroups did not rate railroad crossings as most hazardous. Those driving over 12,500 miles per year and college graduates rated it second to a crossroad. Respondents in the age group 20-29 considered railroad grade crossings to be the third most hazardous situation. Those respondents in the 20 to 29 age group rated a crossroad first, and a yield controlled intersection second. Even in these three cases, railroad grade crossings rated very high on the relative scale. In all categories of subgroups, the stop controlled intersection was rated fourth. Also, the signal controlled intersection and the curve were rated as the two least hazardous situations by all the categories of subgroups.



1 = SIGNAL AHEAD
2 = STOP AHEAD
3 = RAILROAD CROSSING
4 = YIELD AHEAD
5 = CURVE
6 = CROSSROAD

FIGURE 6. RELATIVE SCALES BY SUBGROUPS FOR THE SIX HIGHWAY HAZARDS

A visual inspection of the plot of P'_{ij} versus P''_{ij} was made for all subgroups. No serious departures from a 45 degree straight line were found in any categories of subgroups except in the female, age under 20, non-high school graduates; and those who drove less than 7,500 miles. This is shown in Table 2 where the slope, intercept, and correlation coefficient are given for a least squares fit of all subgroups. Again, it should be noted that the least squares fit is only an indication which aids in evaluating the P'_{ij} versus P''_{ij} plot. Although it would be questionable to accept the results of the three subgroups mentioned, it should be noted that the results were in general agreement with the other subgroups.

An Absolute Scaling for Six Highway Hazards

The paired comparison analysis indicated that railroad grade crossings were relatively more hazardous than the other five hazards. A rating scale was used to indicate how hazardous grade crossings rate on an absolute scale.

After the 259 respondents completed the paired comparison questions, they had seen each of the six hazards a total of five times. They were, therefore, familiar with the six hazards. They were now asked to rate each hazard individually. The respondents were told they would be shown each of the six hazards one at a time as shown in Figure 7. They were told to indicate how hazardous they felt each situation was by marking a number from one (not very hazardous) to seven (very hazardous). The more hazardous the situation the higher the number they should mark. Figure 8 shows an example of the rating scale.

TABLE 2. LEAST SQUARES FIT OF P'_{ij} VERSUS P''_{ij} BY CATEGORIES OF SUBGROUPS FOR THE EVALUATION OF SIX HIGHWAY HAZARDS

Categories of Subgroups	Intercept	Slope	Correlation
All Respondents	.0356	.9279	.9623
Males	.0270	.9440	.9702
Females	.1690	.6426	.7831
Age <20	.1175	.7442	.8558
Age 20-29	.0082	.9696	.9757
Age >29	.0399	.9227	.9603
Non-High School Graduates	.1462	.6811	.8057
High School Graduates	.0554	.8961	.9420
College Graduates	.0155	.9569	.9746
<7500 Miles	.1607	.6563	.7938
7500-12500 Miles	.0083	.9860	.9872
>12500 Miles	.0410	.9165	.9609

Slide 1

FIGURE 7. AN EXAMPLE OF THE RATING SCALE PRESENTATION

How hazardous a situation is shown?

1 2 3 4 5 6 7

NOT Very Hazardous |__|__|__|__|__|__| Very Hazardous

FIGURE 8. AN EXAMPLE OF THE RATING SCALE ANSWER FORM

Table 3 shows the mean, standard deviation, and the distribution of responses for the 259 respondents. As can be seen from the table, the crossroad, the yield controlled intersection, the railroad crossing, and the curve could only be considered moderately hazardous. The mean ranged from a high of 4.93 for the crossroad to a low of 4.22 for the curve. The distribution of responses also shows that less than 20 percent of the respondents rated any of the four hazards with the highest value of seven.

A value of four on the rating scale can be taken as indifference. The respondents were, therefore, indifferent about the hazard at stop controlled intersections. The mean rating for stop controlled intersections was 4.00. The respondents gave a signalized intersection a mean rating of 3.37. The data indicates the respondents considered signalized intersections as less than hazardous.

Overall, the data seems to indicate that only four hazards are even moderately hazardous. The respondents definitely do not feel strongly toward either extreme.

An Absolute Scaling by Subgroups for Six Highway Hazards

The same subgroups used in the paired comparison analysis were again used in the rating scale analysis. As can be seen in Table 4, the results for all the categories of subgroups are basically the same. The results for all the subgroups indicated that the situations were only moderately hazardous.

A contingency test was used to determine if the distribution of responses was independent of the subgroups. As shown in Table 5, only

TABLE 3. THE MEAN, STANDARD DEVIATION, AND DISTRIBUTION OF RESPONSES FOR THE RATING SCALE FOR THE EVALUATION OF HIGHWAY HAZARDS

HAZARD	No Response	SCALE VALUE							Mean	Standard Deviation
		1	2	3	4	5	6	7		
Signal Ahead	1* (0.4)**	18 (6.9)	56 (21.6)	63 (24.3)	75 (29.0)	30 (11.6)	12 (4.6)	4 (1.5)	3.37	1.34
Stop Ahead	1 (0.4)	27 (10.4)	29 (8.5)	41 (15.8)	52 (20.1)	50 (19.3)	30 (11.6)	29 (11.2)	4.00	1.80
Railroad Crossing	2 (0.8)	13 (5.0)	22 (8.5)	35 (13.5)	47 (18.1)	48 (18.5)	54 (20.8)	38 (14.7)	4.59	1.72
Yield Ahead	1 (0.4)	6 (2.3)	28 (10.8)	26 (10.0)	50 (19.3)	68 (26.2)	54 (20.8)	26 (10.0)	4.60	1.55
Curve Ahead	1 (0.4)	19 (7.3)	37 (14.3)	32 (12.4)	52 (20.1)	47 (18.1)	40 (15.4)	31 (12.0)	4.22	1.79
Crossroad	2 (0.8)	6 (2.3)	15 (5.8)	27 (10.4)	47 (18.1)	56 (21.6)	59 (22.8)	47 (18.1)	4.93	1.57

*Top number indicates the number of responses.

**Bottom number indicates the percent of the 259 total respondents.

TABLE 4. ABSOLUTE SCALES BY CATEGORIES OF SUBGROUPS FOR THE EVALUATION OF HIGHWAY HAZARDS

HAZARD	SUBGROUP AND				
	All Respondents (259)	Males (209)	Females (50)	Age <20 (94)	Age 20-29 (85)
Signal	3.37* (1.34)**	3.33 (1.28)	3.54 (1.54)	3.45 (1.34)	3.14 (1.26)
Stop	4.00 (1.80)	4.09 (1.76)	3.98 (1.97)	4.15 (1.80)	3.72 (1.78)
Railroad	4.59 (1.72)	4.46 (1.74)	5.14 (1.54)	5.15 (1.55)	4.60 (1.74)
Yield	4.60 (1.55)	4.57 (1.56)	4.70 (1.53)	4.44 (1.58)	4.74 (1.47)
Curve	4.22 (1.79)	4.22 (1.79)	4.24 (1.80)	4.32 (1.85)	3.52 (1.65)
Crossroad	4.93 (1.57)	4.96 (1.55)	4.82 (1.66)	4.82 (1.67)	5.01 (1.57)

*Average rating.

**Standard deviation.

TABLE 4, cont.

NUMBER OF RESPONDENTS						
Age >29 (80)	Non-H.S. Grads (88)	H.S. Grads (83)	College Grads (88)	<7500 Miles (87)	7500-12500 Miles (76)	>12500 Miles (83)
3.52 (1.40)	3.45 (1.25)	3.12 (1.40)	3.51 (1.35)	3.43 (1.49)	3.43 (1.22)	3.25 (1.32)
4.34 (1.78)	4.24 (1.75)	3.82 (1.85)	4.12 (1.79)	4.05 (1.83)	4.20 (1.93)	3.90 (1.68)
3.91 (1.66)	5.01 (1.58)	4.52 (1.82)	4.24 (1.68)	4.91 (1.63)	4.79 (1.70)	4.10 (1.76)
4.63 (1.59)	4.45 (1.55)	4.48 (1.51)	4.85 (1.57)	4.48 (1.43)	4.69 (1.61)	4.54 (1.65)
4.86 (1.61)	4.34 (1.81)	4.17 (1.70)	4.15 (1.86)	4.30 (1.77)	3.38 (1.75)	4.40 (1.77)
4.98 (1.45)	4.90 (1.64)	4.95 (1.62)	4.95 (1.44)	4.82 (1.59)	5.07 (1.43)	4.86 (1.65)

TABLE 5. CONTINGENCY TESTS BY SUBGROUPS FOR THE EVALUATION OF SIX HIGHWAY HAZARDS

Hazard	Subgroups	Degrees of Freedom	Chi Square Calculated	Chi Square at .01	Reject Null Hypothesis?
Signal	Sex	3	.3423	11.3	No
	Age	6	10.3	16.8	No
	Education	6	7.90	16.8	No
	Miles	8	5.12	20.1	No
Stop	Sex	3	1.98	11.3	No
	Age	8	6.61	20.1	No
	Education	12	5.05	26.2	No
	Miles	12	11.23	26.2	No
Railroad	Sex	3	7.20	11.3	No
	Age	10	26.2	23.2	Yes
	Education	10	17.4	23.2	No
	Miles	10	12.7	23.2	No
Yield	Sex	3	3.34	11.3	No
	Age	6	5.06	16.8	No
	Education	6	4.69	16.8	No
	Miles	6	1.81	16.8	No
Curve	Sex	3	1.46	11.3	No
	Age	6	25.6	16.8	Yes
	Education	12	4.58	26.2	No
	Miles	12	9.51	26.2	No
Crossroad	Sex	4	3.17	13.3	No
	Age	10	9.02	23.2	No
	Education	10	7.00	23.2	No
	Miles	8	3.36	20.1	No

Null Hypothesis: The distribution of responses is independent of the subgroup.

CHAPTER V. PRIORITIES FOR ALLOCATING HIGHWAY TAXES

The objective of this part of the research was to evaluate driver priorities for improving the safety at railroad grade crossings and several other highway improvements. The eight areas chosen for evaluation were of approximately the same order of magnitude of cost. The eight areas were:

1. improve warning devices at railroad grade crossings;
2. improve the road surface on major highways;
3. improve signs giving directions;
4. provide mowing of grass along the sides of highways;
5. install more traffic lights;
6. improve roadside rest areas;
7. improve maintenance of painted lines on roads; and
8. provide free emergency telephones that are connected only to the highway department and the police department.

The method of evaluation chosen was a rating scale. As shown in Figure 9, each item was written above a scale from one to seven.

IMPROVE WARNING DEVICES AT RAILROAD CROSSINGS

1 2 3 4 5 6 7

UNimportant | | | | | | | Important

FIGURE 9. AN EXAMPLE OF THE RATING SCALE FORMAT

for the age subgroup was the hypothesis of independence rejected at an alpha level of .01 for both the railroad crossing and the curve. It was found that railroad crossings were rated less hazardous as age increased. Also, those over 29 found a curve more hazardous than did those under 20, while those between 20 and 29 felt a curve to be least hazardous.

Summary

It has been shown that railroad grade crossings are considered by the respondents to be relatively more hazardous than signalized intersections, yield controlled intersections, crossroads, and cruves. However, the respondents consider only four of the six highway situations to be even moderately hazardous. An analysis using four subgroups resulted in the same conclusions as were made for the 259 respondents.

Respondents were told to indicate the importance of each item in receiving highway taxes. The scale ranged from one, indicating the item was unimportant, to seven, which indicated that the item was important. The higher the number indicated, the more money the respondent felt should be placed on the corresponding alternative.

Driver Preferences for Highway Improvements

The results of the rating scale for the 259 respondents are shown in Table 6. The numbers shown are the distribution of responses, the average responses, and the standard deviations. The respondents gave the improvement of the road surface the highest average rating of 5.77. The standard deviation was 1.38. A value of 5.77 indicates a relatively high degree of importance considering the maximum possible score is seven. Table 6 also shows that only 16 percent gave a rating of four or less. This result agrees with work done by Heathington (15) where it was found that Chicago drivers also considered the repair of pavement the most important of ten alternative transportation improvements for expressways.

Improving the safety at railroad grade crossings received an average rating of 5.74. The standard deviation was 1.47. This rating was a close second to improving road surfaces. Nearly 44 percent of the respondents indicated the highest degree of importance (a rating of seven) for improving the safety at railroad grade crossings. Less than 19 percent of the respondents indicated a response of four or less. The rating indicates a high degree of importance for improving safety at railroad grade crossings.

TABLE 6. THE MEAN, STANDARD DEVIATION, AND DISTRIBUTION OF RESPONSES FOR THE RATING SCALE FOR THE ALTERNATIVE HIGHWAY IMPROVEMENTS

IMPROVEMENT	No Response	SCALE VALUE							Mean	Standard Deviation
		1	2	3	4	5	6	7		
Traffic Lights	3* (1.1)**	19 (7.3)	29 (11.2)	43 (16.6)	63 (24.3)	53 (20.5)	28 (10.8)	21 (8.1)	4.05	1.64
Road Surface	4 (1.5)	3 (1.1)	6 (2.3)	9 (3.5)	25 (9.7)	43 (16.6)	68 (26.2)	101 (39.0)	5.77	1.38
Directional Signs	4 (1.5)	7 (2.7)	11 (4.2)	30 (11.6)	51 (19.7)	51 (19.7)	46 (17.8)	59 (22.8)	4.97	1.62
Mowing Grass	4 (1.5)	41 (15.8)	68 (26.2)	51 (19.7)	42 (16.2)	25 (9.7)	13 (5.0)	15 (5.8)	3.16	1.69
Railroad Crossings	4 (1.5)	3 (1.1)	8 (3.1)	12 (4.6)	26 (10.0)	42 (16.2)	53 (20.5)	111 (42.8)	5.74	1.47
Rest Areas	4 (1.5)	35 (13.5)	38 (14.7)	40 (15.4)	54 (20.8)	38 (14.7)	27 (10.4)	23 (8.9)	3.76	1.82
Painted Lines	5 (1.9)	2 (0.8)	14 (5.4)	18 (6.9)	38 (14.7)	42 (16.2)	49 (18.9)	91 (35.1)	5.42	1.58
Emergency Telephones	6 (2.3)	18 (6.9)	19 (7.3)	19 (7.3)	43 (16.6)	46 (17.8)	45 (17.4)	63 (24.3)	4.84	1.86

*Number of responses.

**Percent of 259 total responses.

Third with an average rating of 5.42 was the improvement of the maintenance of painted lines. The corresponding standard deviation was 1.58. As seen in Table 6, more than 70 percent of the responses were higher than the midpoint value of four. Fourth with an average response of 4.97 and a standard deviation of 1.62 is the improvement of signs giving directions. This item is nearly a full scale division below the top rated item to improve road surfaces. The number of responses over four was 60 percent. Improvement of directional signs, therefore, could only be considered moderately important. Just below the improvement of directional signs is the provision of emergency telephones along highways. This item had a mean of 4.84 and a standard deviation of 1.86. It also could be considered moderately important with approximately 60 percent indicating responses over four on the scale.

Rated sixth with a mean of 4.05 and a standard deviation of 1.64 was the installation of more traffic lights. Looking at the distribution of results, only four percent more of the respondents rated traffic signals above four than did those who rated it below four. At best, installing more traffic signals could only be considered slightly important.

The remaining two items have ratings below the indifference point of four. They were considered to be unimportant by more people than thought they were important. Rated seventh with a mean of 3.76 and a standard deviation of 1.82 was the improvement of roadside rest areas. Last with a mean of 3.16 and a standard deviation of 1.69 was the provision of the mowing of grass along the sides of highways.

Driver Preferences by Subgroups for Highway Improvements

A contingency test was made for subgroups based on sex, age, education, and miles driven per year to determine if the distribution of responses was independent of the subgroup. As is shown in Table 7, the hypothesis of independence is rejected in two subgroups at an alpha level of 0.01. This was the education subgroup for the improvement of road surfaces and the age subgroup for the improvement of the maintenance of painted lines.

Table 8 shows the means and standard deviations for all categories of subgroups. The improvement of road surfaces is shown to be considered most important by high school graduates, less important by non-high school graduates, and least important by college graduates. The ratings ranged from 5.44 to 6.18 for the three education categories. This indicates a high degree of importance by all the respondents for the improvement of the maintenance of road surfaces.

The improvement of the maintenance of painted lines was considered more important as age increased. The average rating of 6.0 for those over 29 was nearly a full scale division above an average of 5.18 for those age 20 to 29 and an average of 5.17 for those under 20. The average of 6.0 indicates a very high degree of importance for the maintenance of painted lines for those over age 29. The remainder of the respondents only considered painted lines as moderately important.

Summary

The improvement of the safety at railroad grade crossings was considered very important by the 259 respondents. The respondents also

TABLE 7. CONTINGENCY TESTS BY SUBGROUPS FOR THE ALTERNATIVE HIGHWAY IMPROVEMENTS

Alternative	Subgroups	Degrees of Freedom	Chi Square Calculated	Chi Square at .01	Reject Null Hypothesis?
Traffic Lights	Sex	4	1.14	13.3	No
	Age	8	10.5	20.1	No
	Education	12	4.99	26.2	No
	Miles	12	13.8	26.2	No
Road Surface	Sex	2	6.56	9.21	No
	Age	6	9.03	16.8	No
	Education	8	21.0	20.1	Yes
	Miles	6	6.48	16.8	No
Directional Signs	Sex	4	6.03	13.3	No
	Age	8	15.2	20.1	No
	Education	8	5.74	20.1	No
	Miles	8	10.0	20.1	No
Mowing Grass	Sex	4	.653	13.3	No
	Age	10	14.0	23.2	No
	Education	8	18.5	20.1	No
	Miles	8	8.20	20.1	No
Railroad Crossings	Sex	2	5.42	9.21	No
	Age	6	10.6	16.8	No
	Education	6	16.0	16.8	No
	Miles	6	6.89	16.8	No
Rest Areas	Sex	2	7.63	9.21	No
	Age	10	11.4	23.2	No
	Education	12	5.61	26.2	No
	Miles	8	9.55	20.1	No
Painted Lines	Sex	4	2.08	13.3	No
	Age	8	20.8	20.1	Yes
	Education	8	9.77	20.1	No
	Miles	8	10.1	20.1	No
Emergency Telephones	Sex	4	2.24	13.3	No
	Age	8	10.5	20.1	No
	Education	8	12.0	20.1	No
	Miles	8	7.57	20.1	No

Null Hypothesis: The distribution of responses is independent of the subgroup.

TABLE 8. ABSOLUTE SCALES VALUES BY SUBGROUPS FOR THE ALTERNATIVE HIGHWAY IMPROVEMENTS

IMPROVEMENT		SUBGROUPS AND			
	All Respondents (259)	Males (209)	Females (50)	Age <20 (94)	Age 20-29 (85)
Traffic Lights	6* 4.05** (1.64)***	6 4.01 (1.65)	6 4.24 (1.58)	6 4.18 (1.61)	6 3.79 (1.48)
Road Surface	1 5.77 (1.38)	1 5.69 (1.44)	2 6.10 (1.04)	2 5.79 (1.37)	1 6.04 (1.28)
Directional Signs	4 4.97 (1.62)	4 4.94 (1.65)	4 5.08 (1.47)	5 4.70 (1.60)	4 5.02 (1.60)
Mowing Grass	8 3.16 (1.69)	8 3.18 (1.72)	8 3.10 (1.57)	8 3.22 (1.62)	8 2.82 (1.53)
Railroad Crossings	2 5.74 (1.47)	2 5.62 (1.56)	1 6.22 (0.93)	1 6.13 (1.11)	2 5.46 (1.57)
Rest Areas	7 3.76 (1.82)	7 3.87 (1.86)	7 3.32 (1.60)	7 3.47 (1.72)	7 3.61 (1.79)
Painted Lines	3 5.42 (1.58)	3 5.46 (1.57)	3 5.24 (1.66)	3 5.17 (1.54)	3 5.18 (1.70)
Emergency Telephones	5 4.84 (1.86)	5 4.80 (1.89)	5 5.04 (1.71)	4 5.09 (1.66)	5 4.67 (1.98)

*Relative rank.

**Average rating.

***Standard deviation.

TABLE 8, cont.

NUMBER OF RESPONDENTS						
Age >29 (80)	Non-H.S. Grads (88)	H.S. Grads (83)	College Grads (88)	<7500 Miles (87)	7500-12500 Miles (76)	>12500 Miles (83)
7 4.19 (1.81)	6 4.16 (1.64)	6 4.01 (1.62)	6 3.99 (1.66)	6 4.07 (1.54)	6 3.97 (1.79)	6 4.04 (1.66)
3 5.46 (1.45)	2 5.72 (1.42)	1 6.18 (1.24)	2 5.44 (1.38)	2 5.83 (1.45)	1 5.88 (1.34)	2 5.57 (1.35)
4 5.24 (1.63)	5 4.81 (1.64)	4 5.00 (1.72)	4 5.10 (1.49)	5 4.85 (1.65)	4 5.25 (1.50)	4 4.84 (1.65)
8 3.46 (1.89)	8 3.12 (1.58)	8 3.59 (1.90)	8 2.79 (1.50)	8 2.99 (1.59)	8 3.42 (1.85)	8 3.13 (1.68)
2 5.58 (1.66)	1 6.08 (1.14)	2 5.91 (1.44)	3 5.23 (1.67)	1 5.91 (1.29)	2 5.68 (1.65)	3 5.55 (1.50)
6 4.30 (1.91)	7 3.61 (1.78)	7 3.73 (1.92)	7 3.95 (1.78)	7 3.52 (1.72)	7 3.81 (1.83)	7 4.01 (1.96)
1 6.00 (1.36)	3 5.16 (1.57)	3 5.46 (1.72)	1 5.66 (1.43)	3 5.30 (1.54)	3 5.42 (1.68)	1 5.58 (1.57)
5 4.75 (1.93)	4 5.13 (1.69)	4 5.00 (1.91)	5 4.42 (1.91)	4 4.90 (1.87)	5 5.03 (1.77)	5 4.53 (1.98)

considered it important that highway taxes be spent on the improvement of road surfaces, and the improvement of the maintenance of painted lines. A moderately important priority was given to the improvement of directional signs and the provision of emergency telephones. The installation of more traffic signals was rated indifferent. The improvement of roadside rest areas and the mowing of grass along the sides of highways were both rated as relatively unimportant.

CHAPTER VI. AN EVALUATION OF SEVERAL WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

The third objective of this research was to propose and evaluate new advance warning systems for railroad grade crossings. Three new systems were proposed for evaluation relative to two existing systems. This chapter summarizes the evaluation of five alternative warning systems for highway-railway grade crossings.

There are five basic senses with which one can receive information. They are sight, taste, smell, touch, and hearing. It can easily be seen that taste, smell, and touch play only a minor role in driving. There are of course special situations where these three minor senses become important. For example, the road may have artificial bumps placed on the road surface to attract the attention of a driver. These rumble strips or jiggle bars, as they are called, use the sense of "feel" to alert the driver. Nevertheless, sight and sound remain the important modes of communication for drivers.

The three new advance warning systems are based on the previous research as reviewed in Chapter II. Two proposed systems used visual communication. A changeable message advance warning sign was the result of work on an FDIS (14). A device similar to the dashboard display of ERGS (24) was used to provide a visual in-car message. The third and last new system was an audio in-car message. This system was

patterned after the roadside communication subsystem of the DAIR (12) system. An audio warning system external to the vehicle was not considered in this research.

Two existing systems were included in the analysis: One was the active flashing lights and the other was a passive system consisting only of warning signs. All five warning systems are shown in Figure 10. It can be seen that the same highway scene was used with the appropriate warning devices being photographically added.

A Relative Scaling of Warning Systems

The method of paired comparisons was used to evaluate relative preferences of drivers for the five alternative warning systems for use at grade crossings. The respondents were shown the five hazards two at a time. A total of 10 pairs of hazards were shown. The respondents were asked to indicate which of the two warning devices were more desirable.

Figure 11 shows the results of the ranking by the 259 respondents. The actual calculations are shown in Appendix B. By far the most desirable method of warning was the changeable message sign. It has a relative ranking of 1.39. The changeable message sign was well above the standard flashing lights which had a rating of 1.00. Third with a rating of 0.60 was the in-car audio message, followed closely by the in-car visual message with a rating of 0.52. By far the least desirable method of warning was the passive warning sign with a relative rating of 0.00.

In order to evaluate the results obtained by the paired comparison model, observed proportions (P'_{ij}) were plotted against the

Changeable Message Sign

Standard Flashing Lights

In-Car Audio Message

In-Car Visual Message

Passive Warning Sign

FIGURE 10. PHOTOGRAPHS OF THE WARNING SYSTEMS
FOR HIGHWAY-RAILWAY GRADE CROSSINGS

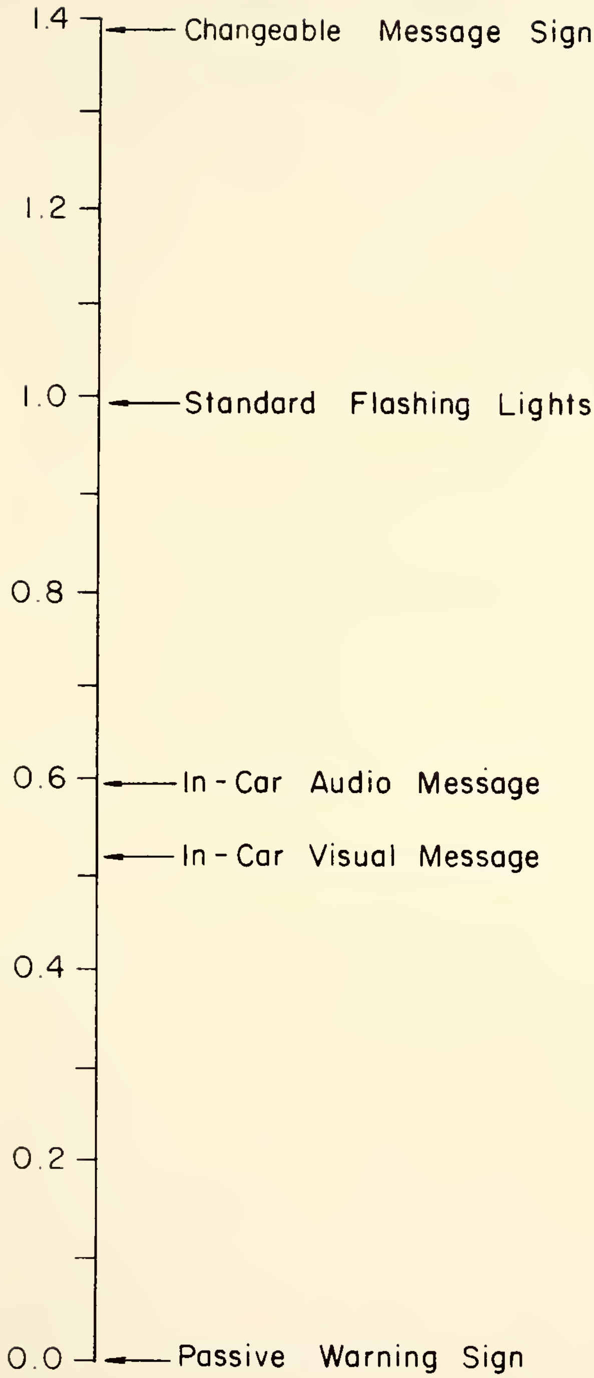


FIGURE 11. A RELATIVE SCALING OF WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

calculated proportions (P''_{ij}). This P'_{ij} versus P''_{ij} plot is shown in Figure 12. The plot indicates a reasonable approximation of a 45 degree straight line through the origin. Another indicator used to evaluate the model was a least squares fit of the P'_{ij} versus P''_{ij} data. If the model was an exact fit, the slope would be 1.00, the intercept would be 0.00, and the simple correlation would be 1.00. The actual results indicated a slope of 1.00, an intercept of -0.02, and a correlation of 0.99. These results tend to indicate a good fit of the observed data by the paired comparison model.

A Relative Scaling by Subgroups of Warning Systems

In order to determine if groups within the sample had different preferences, an analysis was made for various subgroups. These are the same subgroups as in previous parts of the research. Figure 13 shows the results of the paired comparison analysis for the eleven categories of the four subgroups and for all the respondents. The results indicate general agreement for all subgroups. The changeable message sign was rated first by all subgroups. The first choice was also well above the second rated standard flashers. Again, all subgroups rated flashers second. The third and fourth choice for all subgroups was the in-car devices. Most subgroups rated the audio device above the visual device. Those respondents who drove more than 12,500 miles per year, and those over age 29, rated the visual in-car device over the audio device. The least preferred method of warning for all subgroups was the passive warning sign.

Plots were made of the P'_{ij} versus P''_{ij} for all subgroups. These plots are not included, but they all indicated a good fit of the data.

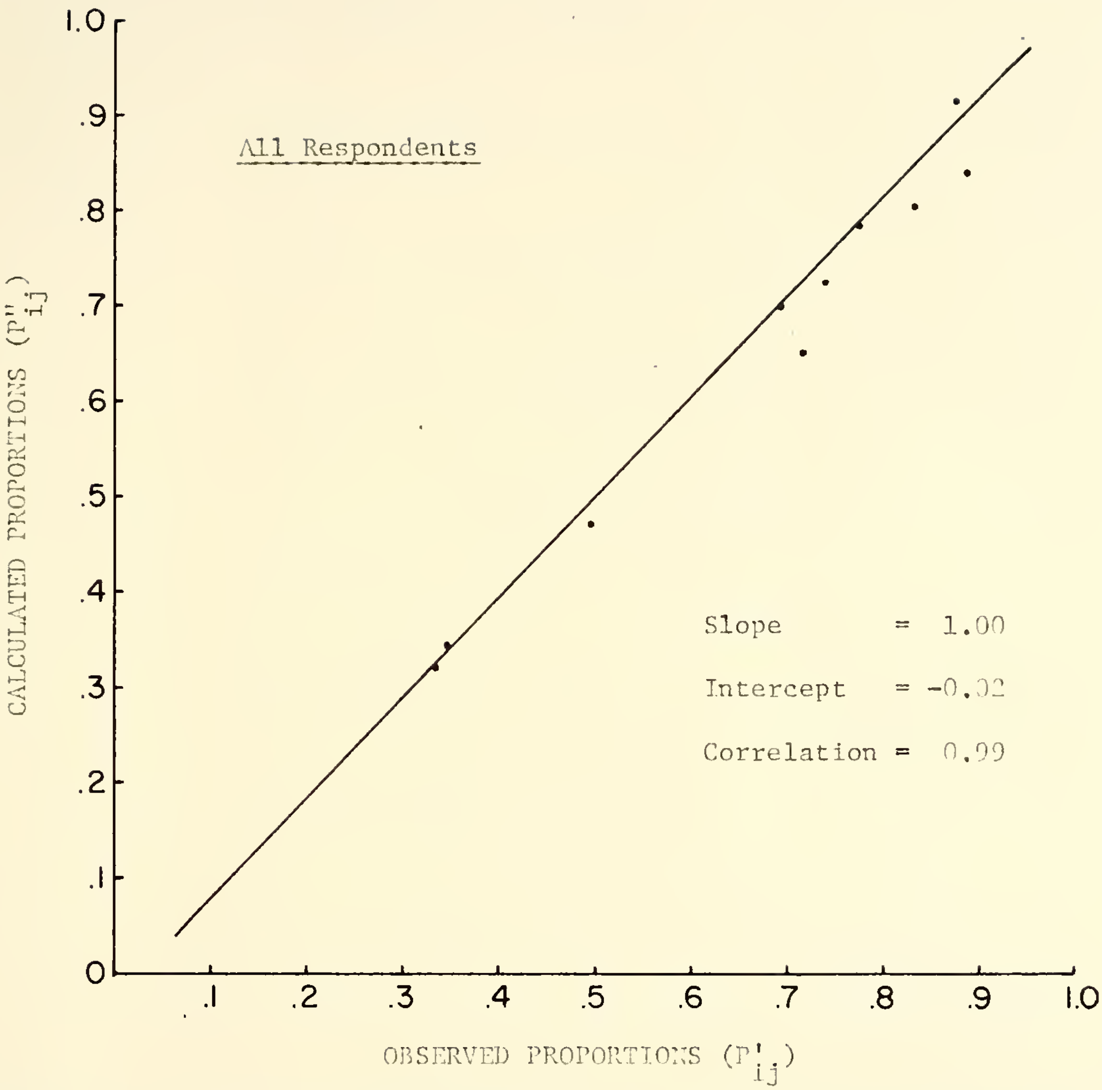
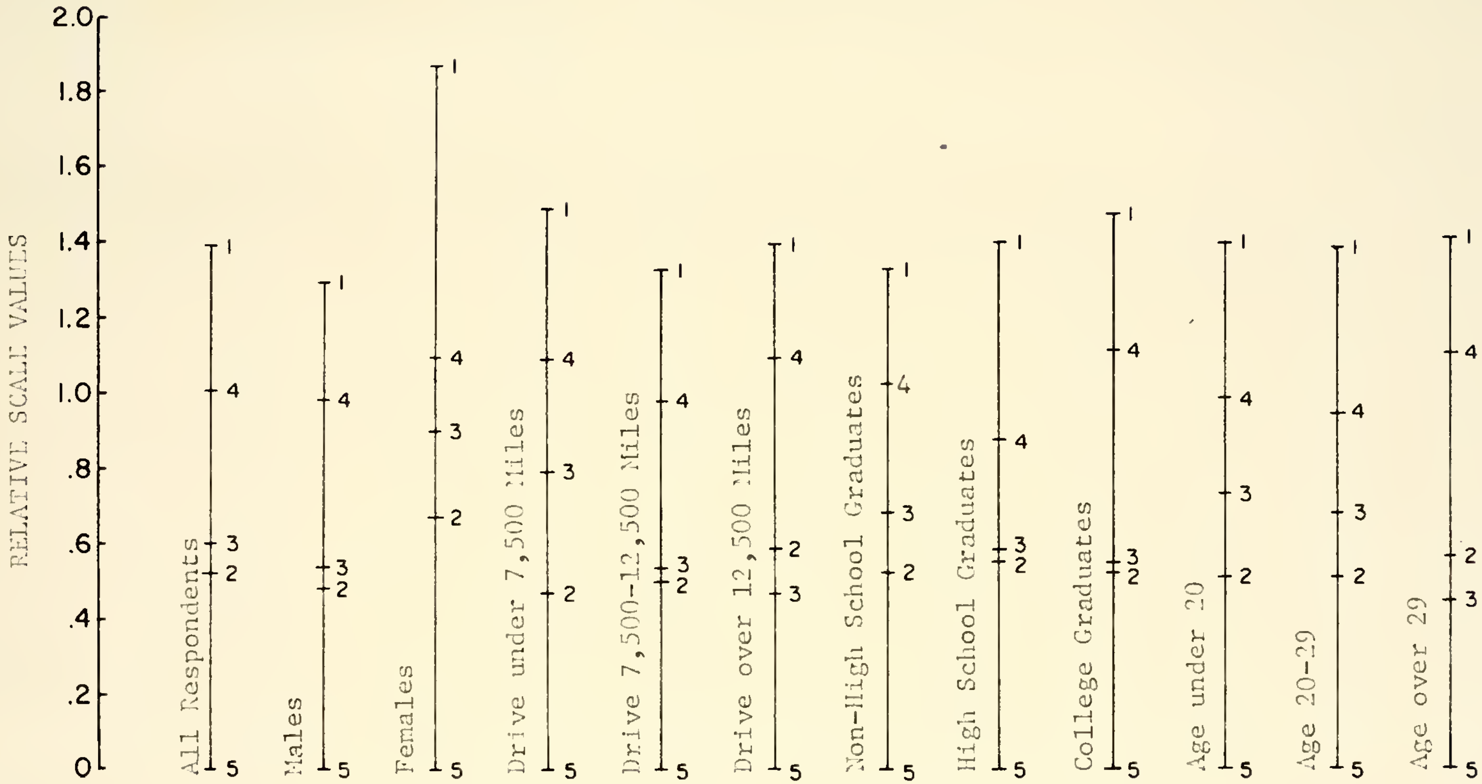


FIGURE 12. CALCULATED VERSUS OBSERVED PROPORTIONS FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS



1 = Changeable Message Sign
2 = In-Car Visual Message
3 = In-Car Audio Message
4 = Standard Flashing Lights
5 = Passive Warning Sign

FIGURE 13. RELATIVE SCALES BY SUBGROUPS FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

A least squares fit of the P'_{ij} versus P''_{ij} was also made as an indicator of the validity of the model. As shown in Table 9, all the slopes approach 1.00, the intercepts approach 0.00, and the correlations approach 1.00. These results also indicated a relatively good fit of the paired comparison model to the data for all subgroups.

An Absolute Scaling of Warning Systems

The paired comparison analysis gave a relative scale indicating that a changeable message sign was the most desirable of five alternative methods of warning. The relative desirability of the warning systems does not give us a complete picture. It is also important to know on an absolute scale the desirability of the warning systems. Therefore the next question to be answered is how important are the alternative methods of warning on an absolute scale.

The method of evaluation selected was a rating scale as shown in Figure 14. The respondents were shown a slide of a warning system and told to mark their response on the rating scale.

Slide 1.

	1	2	3	4	5	6	7	
Undesirable								Desirable

FIGURE 14. AN EXAMPLE OF A RATING SCALE FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

The scale ranged from one (undesirable) to seven (desirable). The higher the number selected, the more desirable the respondents considered the warning system. After completion of the paired comparison question, the respondents were shown the five methods of warning one at

TABLE 9. LEAST SQUARES FIT OF P'_{ij} VERSUS P''_{ij} BY CATEGORIES OF SUBGROUPS FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

Categories of Subgroups	Intercept	Slope	Correlation
All Respondents	-.0160	1.0037	.9894
Males	-.0066	.9926	.9842
Females	-.0329	1.0136	.9842
Age <20	-.0229	.9583	.9848
Age 20-29	-.0105	.9922	.9710
Age >29	-.0114	.9880	.9684
Non-High School Graduates	.0121	.9726	.9914
High School Graduates	.0033	.9724	.9678
College Graduates	-.0391	1.0312	.9878
<7500 Miles	.0108	.9734	.9895
7500-12500 Miles	-.0219	1.0127	.9907
>12500 Miles	-.0250	1.0063	.9718

a time. They were told to indicate their response on the appropriate scale on the answer sheet.

The results are shown in Table 10 for all 259 respondents. The variable message advance warning sign had a mean rating of 6.03 and a standard deviation of 1.43. The distribution of responses is also shown in Table 10. It can be seen that the variable message sign was given the highest rating of seven by over 56 percent of the respondents. The changeable message sign was considered to be a very desirable method of warning by the majority of the respondents.

The standard flashing lights had a mean of 5.17, and a standard deviation of 1.49. The flashers were nearly a full scale division below the changeable message sign. Only 22.8 percent of the respondents gave it a rating of seven, but a total of 69.5 percent rated it above four on the scale. The flashers could be considered moderately desirable.

Lower down on the scale with a mean of 4.19 and a standard deviation of 2.03 was the in-car visual message. The in-car audio message had a mean of 4.07 and a standard deviation of 1.89. As indicated by the distribution of responses, only about 10 percent more of the respondents rated these devices above four than did those who rated below four. Also, more than 16 percent rated each device with the lowest rating of one. At best, considering that a value of four is indifference, the respondents considered the in-car devices as slightly desirable.

The passive sign was rated lowest with a mean of 3.37 and a standard deviation of 1.57. Passive signs were rated less than four by

TABLE 10. THE MEAN, STANDARD DEVIATION, AND DISTRIBUTION OF RESPONSES FOR THE EVALUATION OF WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

METHOD	No Response	SCALE VALUE							Mean	Standard Deviation
		1	2	3	4	5	6	7		
Passive Sign	0* (0.0)**	36 (13.9)	47 (18.1)	50 (19.3)	68 (26.2)	35 (13.5)	14 (5.4)	9 (3.5)	3.37	1.57
Flashing Lights	1 (0.4)	5 (1.9)	10 (3.9)	17 (6.6)	46 (17.8)	65 (25.1)	56 (21.6)	59 (22.8)	5.17	1.49
Variable Message	1 (0.4)	4 (1.5)	3 (1.1)	15 (5.8)	19 (7.3)	22 (8.5)	49 (18.9)	146 (56.4)	6.03	1.43
In-Car Visual	0 (0.0)	42 (16.2)	18 (6.9)	31 (12.0)	46 (17.8)	57 (22.0)	40 (15.4)	25 (9.7)	4.07	1.89
In-Car Audio	0 (0.0)	45 (17.4)	22 (8.5)	21 (8.1)	39 (15.1)	49 (17.8)	48 (18.5)	35 (13.5)	4.19	2.03

*Top number indicates number of responses.

**Bottom number indicates percent of 259 total respondents.

more than 50 percent of the respondents. Only 22.4 percent of the respondents rated the passive sign above four. Passive signs were therefore considered not desirable by the majority of the respondents.

An Absolute Scaling by Subgroups of Warning Systems

Table 11 shows the result of the rating scale for eleven subgroups of the total sample. These are the same subgroups as were used in all parts of the analysis. The results are generally the same for all subgroups. The variable message sign was rated very desirable by all subgroups.

A contingency test was also made to determine if the distribution of responses was independent of the subgroup. The results are shown in Table 12. The hypothesis of independence was not rejected at an alpha level of .01 for any subgroups. There is no reason to believe that any of the subgroups had different preferences for methods of warning.

Summary

The overhead changeable message sign was the most preferred alternative method of warning by all 259 respondents. It was also considered to be very desirable by all the subgroups. In-car devices were rated lower than present flashers. The least preferred method of warning is a passive sign that indicates the same warning at all times.

TABLE 11. ABSOLUTE SCALES BY SUBGROUPS FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

SYSTEM	SUBGROUPS AND				
	All Respondents (259)	Males (209)	Females (50)	Age <20 (94)	Age 20-29 (85)
Passive Sign	3.37* (1.57)**	3.38 (1.54)	3.34 (1.68)	3.22 (1.60)	3.52 (1.53)
Flashers	5.17 (1.49)	5.24 (1.43)	4.88 (1.70)	4.99 (1.53)	4.99 (1.53)
Variable Sign	6.03 (1.43)	6.01 (1.49)	6.12 (1.17)	6.05 (1.40)	5.95 (1.51)
In-Car Radio	4.07 (1.89)	4.01 (1.96)	4.32 (1.54)	4.28 (1.75)	3.88 (1.85)
In-Car Visual Message	4.19 (2.03)	4.15 (2.07)	4.38 (1.85)	4.36 (2.09)	4.01 (1.90)

*Average rating.

**Standard deviation.

TABLE 11, cont.

NUMBER OF RESPONDENTS						
Age >29 (80)	Non-H.S. Grads (88)	H.S. Grads (83)	College Grads (88)	<7500 Miles (87)	7500-12500 Miles (76)	>12500 Miles (83)
3.40 (1.56)	3.35 (1.65)	3.53 (1.56)	3.25 (1.49)	3.33 (1.65)	3.37 (1.65)	3.36 (1.49)
5.58 (1.32)	5.15 (1.59)	5.10 (1.54)	5.26 (1.33)	5.10 (1.57)	5.09 (1.40)	5.41 (1.38)
6.10 (1.39)	6.00 (1.53)	6.04 (1.44)	6.07 (1.34)	6.03 (1.48)	6.03 (1.42)	6.12 (1.38)
4.04 (2.08)	4.30 (1.83)	3.98 (1.88)	3.94 (1.96)	4.09 (1.71)	3.96 (1.98)	4.11 (2.01)
4.19 (2.09)	4.42 (2.12)	4.07 (2.02)	4.08 (1.95)	4.22 (1.98)	4.32 (2.14)	4.05 (1.98)

TABLE 12. CONTINGENCY TESTS BY SUBGROUPS FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

System	Subgroups	Degrees of Freedom	Chi Square Calculated	Chi Square at .01	Reject Null Hypothesis?
1	Sex	4	5.53	13.3	No
	Age	10	15.7	23.2	No
	Education	10	14.4	23.2	No
	Miles	10	7.35	23.2	No
2	Sex	5	5.70	15.1	No
	Age	8	9.35	20.1	No
	Education	8	6.59	20.1	No
	Miles	8	8.38	20.1	No
3	Sex	2	1.98	9.2	No
	Age	8	.707	20.1	No
	Education	8	1.43	20.1	No
	Miles	8	4.06	20.1	No
4	Sex	4	11.5	13.3	No
	Age	8	11.1	20.1	No
	Education	10	7.36	23.2	No
	Miles	12	16.0	26.2	No
5	Sex	6	7.17	16.8	No
	Age	10	12.4	23.2	No
	Education	12	9.44	26.2	No
	Miles	12	11.6	26.2	No

1 = Passive Advance Warning Sign
2 = Standard Flashers
3 = Overhead Variable Message Sign
4 = In-Car Visual Message
5 = In-Car Audio Message

Null Hypothesis: The distribution of responses is independent of the subgroup.

CHAPTER VII. AN EVALUATION OF ALTERNATIVE DISPLAYS FOR USE IN ADVANCE WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

The objective to propose and evaluate new advance warning systems was only partially met in Chapter VI. In order to completely evaluate the proposed new systems, it was necessary to evaluate alternative displays to be used in the advance warning systems. The evaluation of alternative displays is important in order to determine a display with the correct meaning. Economic considerations also make it desirable to have as short a display as possible. The methods of evaluation were the method of paired comparisons and a rating scale.

The evaluation of the alternative messages was made in two parts. The first part of the evaluation concerned messages to be used when a driver had to stop because of the presence, or imminent presence, of a train. The second part of the evaluation concerned messages to be used when there was no train. The simplest alternative for the second condition is to provide no message. If this alternative was accepted, then no analysis would be necessary. It was decided, however, to evaluate the "no message" (no information) alternative with several messages indicating that no hazard existed.

A Relative Scaling for Alternative Displays When a Hazard Exists

Five alternative messages were selected for possible use when a train is blocking the highway or so close to the crossing that it constitutes an imminent hazard to approaching vehicles. The actual messages are shown in Figure 15. The alternatives were shown to the respondents in the same manner and at the same location as used in the hazard evaluation in Chapter VI.

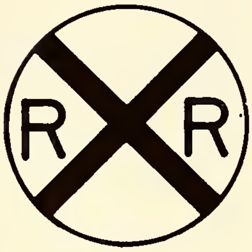
The paired comparison technique was used to evaluate the relative acceptability of the five alternative displays. The results for the 259 respondents are shown in Figure 16. The most preferred display with a relative scale value was "RXR TRACKS BLOCKED/STOP AHEAD." This display both identifies the hazard and tells the driver the necessary action to take. A close second with a 1.27 scale value was the display "RXR CROSSING BLOCKED/STOP AHEAD." This display has the same characteristics as the most preferred display. The only difference is the word "crossing" in place of "tracks."

Third rated was the display "RXR TRACKS BLOCKED." The relative scale value was 0.39. It can be seen that it is very important to the respondents to be told that they should "stop ahead." Except for the words "stop ahead," this display is identical to the top rated display.

The fourth rated display contained all words (no symbols). The display was "RAILROAD CROSSING/TRACKS BLOCKED" and had a scale value of 0.15. Comparing this display with the third rated "RXR TRACKS BLOCKED," one can see that the symbol is apparently recognized and seems to be preferred over the equivalent in words.

TRACKS BLOCKED

STOP AHEAD



CROSSING BLOCKED

STOP AHEAD

TRACKS BLOCKED

RAILROAD CROSSING

TRACKS BLOCKED

RR Xing

STOP AHEAD

FIGURE 15. DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT HIGHWAY-RAILWAY GRADE CROSSINGS

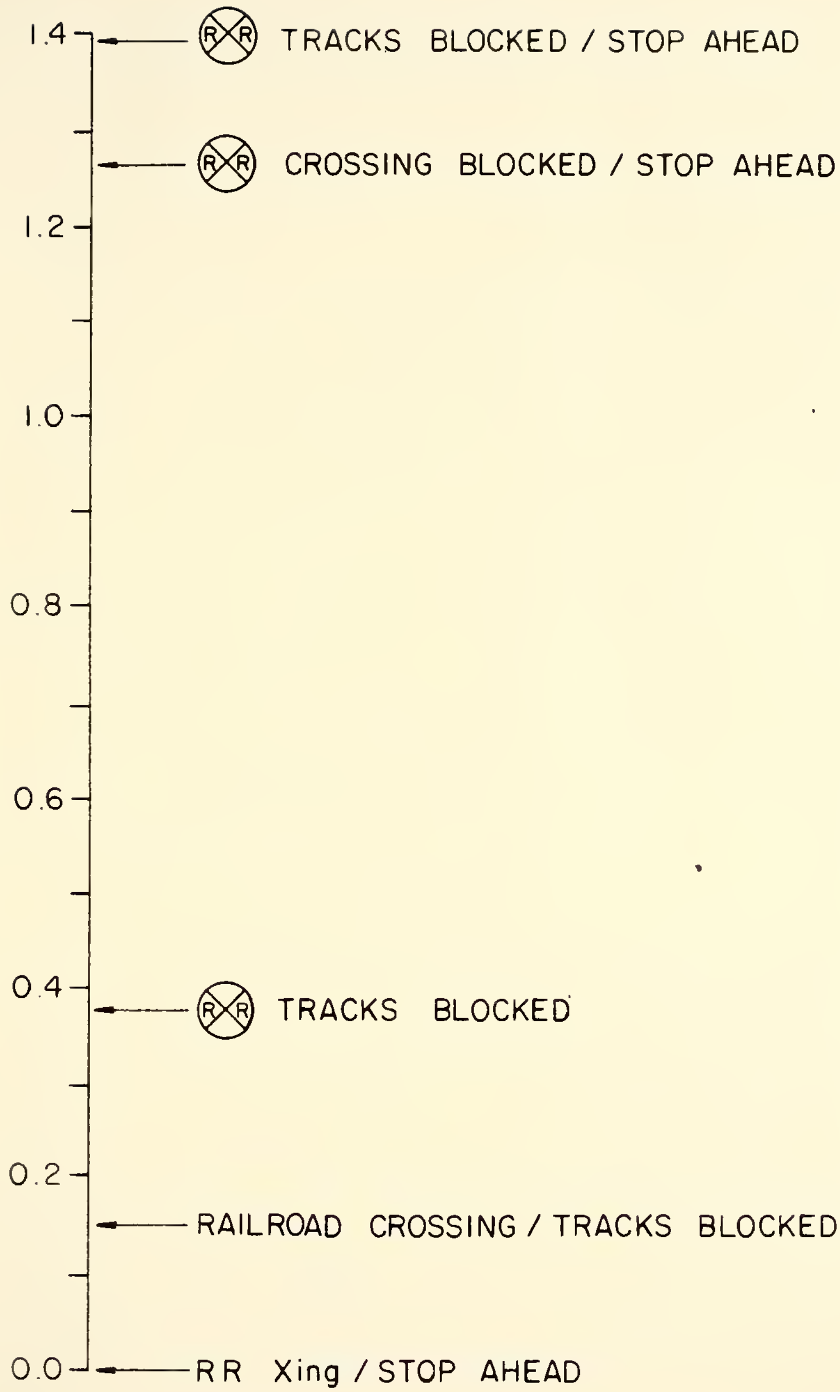


FIGURE 16. A RELATIVE SCALE FOR ALTERNATIVE DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

The last display contained an abbreviation for the railroad symbol plus the stop ahead instruction. The display "RR Xing/STOP AHEAD" had a relative scale value of 0.0. Even with the stop ahead instructions, this display received the lowest rating.

In order to check the validity of the results, the observed proportions (P'_{ij}) were plotted against the calculated proportions (P''_{ij}) based on the paired comparison model. The results are shown in Figure 17. A least squares fit of the P'_{ij} versus P''_{ij} matrix was also made as an indicator of how well the model fit the data. The results were an intercept of 0.02, a slope of 0.95, and a correlation of 0.99. If the model was a perfect fit of the data, the intercept would be 0.00, the slope would be 1.00, and the correlation would also be 1.00. The results indicate a reasonably good fit of the observed data by the paired comparison model.

A Relative Scaling by Subgroups for Displays When a Hazard Exists

The alternative displays were analyzed to see if any subgroups had different preferences. The results are shown in Figure 18. The results of all the subgroups are in general agreement, except for three minor exceptions. Those who drive over 12,500 miles per year and those age 20-29 rated the display " CROSSING BLOCKED/STOP AHEAD" first. The display most preferred by all other subgroups was rated such a close second that any difference in results is minor. The third difference is that females interchanged the fourth and fifth rated displays. This difference is minor since the concern is with the more preferred displays.

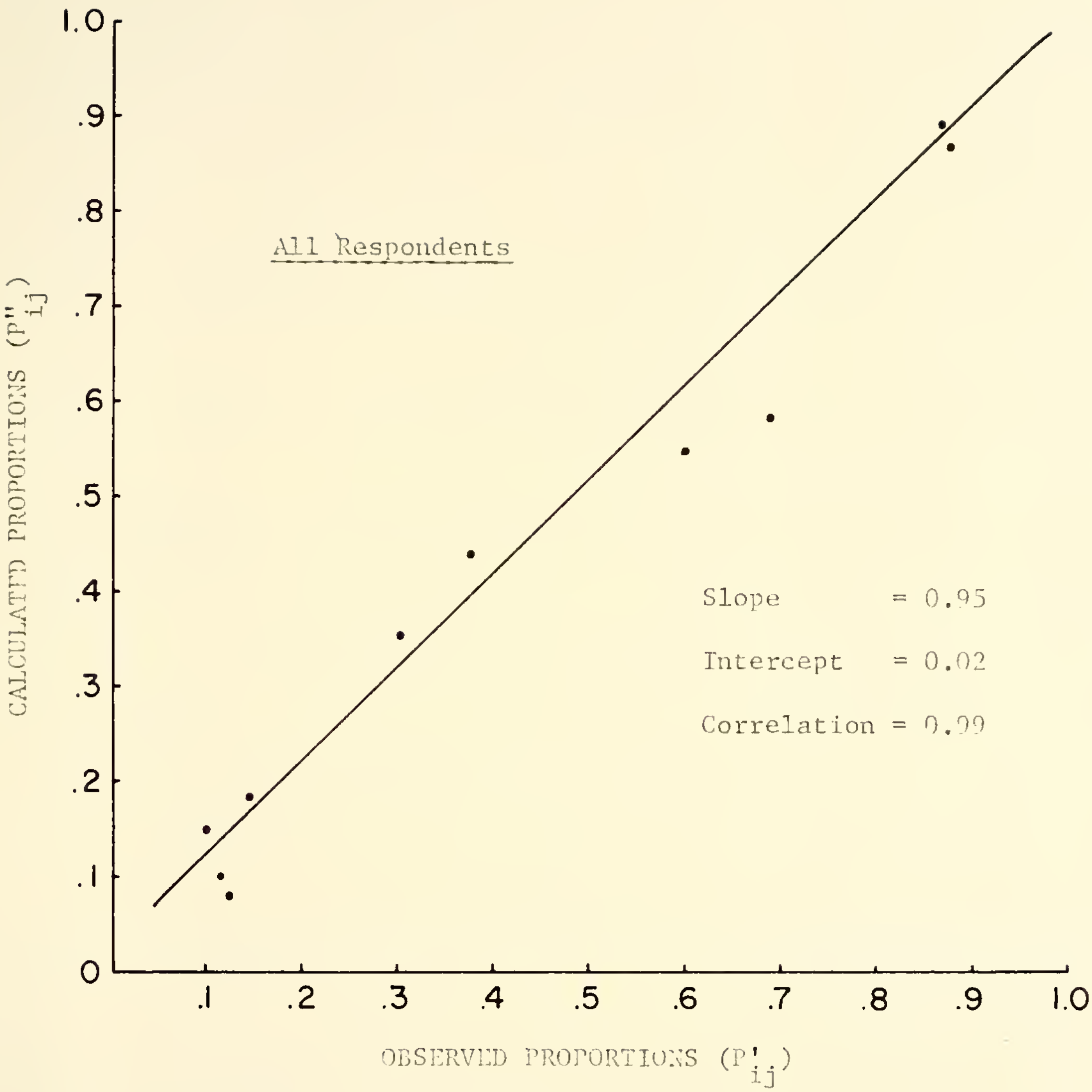
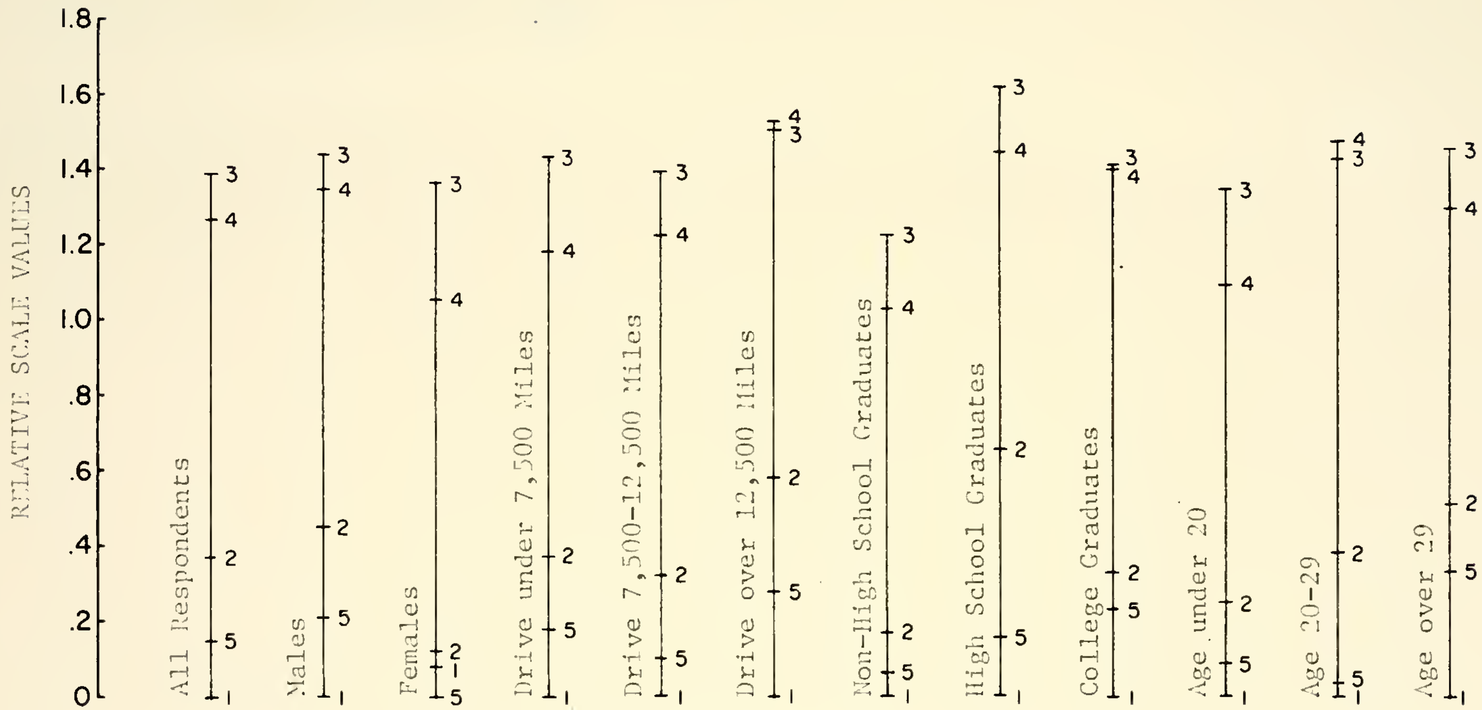


FIGURE 17. CALCULATED VERSUS OBSERVED PROPORTIONS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING



1 = RR Xing/Stop Ahead
2 = Tracks Blocked
3 = Tracks Blocked/Stop Ahead
4 = Crossing Blocked
5 = Railroad Crossing/Tracks Blocked

FIGURE 18. RELATIVE SCALES BY SUBGROUPS FOR ALTERNATIVE DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

The P'_{ij} versus P''_{ij} matrix was also plotted for all subgroups. The results of the plots are reflected in the least squares fit of the data which is shown in Table 13. The paired comparison model was a reasonable fit of the data for all categories of subgroups. There is no reason not to accept the results of the paired comparison analysis for all categories of subgroups.

An Absolute Scaling for Alternative Displays When a Hazard Exists

A rating scale was used to determine an absolute scale for the five alternative displays for an advance warning system when a hazard exists. The five displays were shown to the 259 respondents one at a time. They were asked to indicate, on a scale from one to seven, how acceptable they considered each alternative display, as shown in Figure 19. The higher the number indicated, the more acceptable the respondents considered the display.

The rating scale results are shown in Table 14. The display "

TRACKS BLOCKED/STOP AHEAD" was considered to be very acceptable with a mean rating of 6.19 and a standard deviation of 1.08. Fifty percent of the respondents gave this display the highest rating of seven. Only 8.1 percent of the respondents gave the display a rating of four or less. Also rated very acceptable with a mean of 6.12 and a standard deviation of 1.12 was the display "

CROSSING BLOCKED/STOP AHEAD." Forty-eight percent indicated a rating of seven and only 8.1 percent indicated a rating of four or less. These two alternatives are very similar in absolute preference.

TABLE 13. LEAST SQUARES FIT OF P'_{ij} VERSUS P''_{ij} BY CATEGORIES OF SUBGROUPS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Categories of Subgroups	Intercept	Slope	Correlation
All Respondents	.0240	.9480	.9854
Males	.0232	.9546	.9893
Females	.0300	.9175	.9585
Age <20	.0352	.9275	.9747
Age 20-29	.0190	.9580	.9837
Age >29	.0200	.9483	.9888
Non-High School Graduates	.0243	.9315	.9741
High School Graduates	.0267	.9490	.9911
College Graduates	.0249	.9536	.9833
<7500 Miles	.0310	.9127	.9690
7500-12500 Miles	.0269	.9538	.9865
>12500 Miles	.2081	.9504	.9871

How acceptable is the message shown?

(Example Slide 1)

<u>Example Slide 1</u>

1 2 3 4 5 6 7

UNacceptable Acceptable

FIGURE 19. AN EXAMPLE OF THE RATING SCALE PRESENTATION FOR ALTERNATIVE DISPLAYS FOR ADVANCE WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

TABLE 14. THE MEAN, STANDARD DEVIATION, AND DISTRIBUTION OF RESPONSES FOR DISPLAYS WHEN A HAZARD EXISTS

DISPLAY	No Response	SCALE VALUE							Mean	Standard Deviation
		1	2	3	4	5	6	7		
Number 1	1* (0.4)**	17 (6.6)	57 (22.0)	45 (17.4)	56 (21.6)	43 (16.6)	24 (9.3)	16 (6.2)	3.72	1.64
Number 2	0 (0.0)	8 (3.1)	11 (4.2)	36 (13.9)	62 (23.9)	60 (23.2)	53 (20.5)	29 (11.2)	4.66	1.49
Number 3	1 (0.4)	1 (0.4)	2 (0.8)	4 (1.5)	14 (5.4)	28 (10.8)	80 (30.5)	129 (49.8)	6.19	1.08
Number 4	1 (0.4)	1 (0.4)	2 (0.8)	8 (3.1)	10 (3.9)	36 (13.9)	77 (29.8)	125 (48.3)	6.12	1.12
Number 5	0 (0.0)	14 (5.4)	34 (13.1)	47 (18.1)	54 (20.8)	49 (18.9)	31 (12.0)	30 (11.6)	4.17	1.70

1 = RR Xing/Stop Ahead

2 =  Tracks Blocked

3 =  Tracks Blocked/Stop Ahead

4 =  Crossing Blocked/Stop Ahead

5 = Railroad Crossing/Tracks Blocked

*Top number indicates number of responses.

**Bottom number indicates percent of 259 total respondents.

The display "RXR TRACKS BLOCKED" had a mean of 4.66 and a standard deviation of 1.49. Fifty-four percent of the respondents indicated ratings above four. This display could be considered as moderately acceptable. The display "RAILROAD CROSSING/TRACKS BLOCKED" could only be considered slightly acceptable. It had a mean of 4.17 and a standard deviation of 1.70. Forty-two percent of the respondents indicated a rating above four on the scale.

The display "RR Xing/STOP AHEAD" was considered unacceptable by the respondents. The mean rating was 3.72 and the standard deviation was 1.64. Fifty percent gave it a rating less than four and only thirty-two percent gave it a rating above four.

An Absolute Scaling by Subgroups for Displays When a Hazard Exists

The eleven categories of the four subgroups were again used to determine if any subgroups had different ratings for the display. The results are shown in Table 15. As can be seen, the results are in general agreement with the results for all respondents. The display "RXR TRACKS BLOCKED/STOP AHEAD" was rated very desirable by all subgroups. The average rating was above 6.00 for all categories of all subgroups.

A contingency test was also performed to determine if the distribution of responses was independent of the subgroup at an alpha level of 0.01. The results of the test are shown in Table 16. The hypothesis of independence was rejected for only one subgroup. Males considered the lowest ranked display, "RAILROAD CROSSING/TRACKS BLOCKED" as slightly more unacceptable than did the females.

TABLE 15. ABSOLUTE SCALES BY SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

DISPLAY	SUBGROUPS AND				
	All Respondents (259)	Males (209)	Females (50)	Age <20 (94)	Age 20-29 (85)
1	3.72* (1.64)**	3.71 (1.69)	3.78 (1.42)	3.91 (1.52)	3.55 (1.69)
2	4.66 (1.49)	4.76 (1.44)	4.26 (1.63)	4.52 (1.47)	4.46 (1.48)
3	6.19 (1.08)	6.18 (1.08)	6.20 (1.07)	6.17 (1.03)	6.09 (1.16)
4	6.12 (1.12)	6.12 (1.14)	6.14 (1.09)	6.02 (1.10)	6.10 (1.18)
5	4.17 (1.70)	4.18 (1.73)	4.14 (1.56)	4.54 (1.58)	3.88 (1.63)

1 = RR Xing/Stop Ahead

2 = RXR Tracks Blocked

3 = RXR Tracks Blocked/Stop Ahead

4 = RXR Crossing Blocked/Stop Ahead

5 = Railroad Crossing/Tracks Blocked

*Average rating.

**Standard deviation.

TABLE 15, cont.

NUMBER OF RESPONDENTS

Age >29 (80)	Non-H.S. Grads (88)	H.S. Grads (83)	College Grads (88)	<7500 Miles (87)	7500-12500 Miles (76)	>12500 Miles (83)
3.69 (1.71)	4.11 (1.56)	3.36 (1.63)	3.68 (1.65)	3.67 (1.48)	3.92 (1.72)	3.37 (1.59)
5.04 (1.46)	4.51 (1.57)	4.81 (1.46)	4.67 (1.44)	4.60 (1.52)	4.74 (1.50)	4.76 (1.40)
6.30 (1.04)	6.17 (1.09)	6.22 (1.05)	6.17 (1.10)	6.30 (1.02)	6.13 (1.06)	6.12 (1.14)
6.26 (1.10)	6.02 (1.13)	6.13 (1.17)	6.22 (1.08)	5.99 (1.19)	6.28 (1.06)	6.10 (1.10)
4.04 (1.84)	4.69 (1.61)	3.90 (1.64)	3.90 (1.74)	4.39 (1.61)	4.12 (1.66)	3.88 (1.78)

TABLE 16. CONTINGENCY TESTS BY SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display	Subgroups	Degrees of Freedom	Chi Square Calculated	Chi Square at .01	Reject Null Hypothesis?
1	Sex	4	18.2	13.3	Yes
	Age	12	15.8	26.2	No
	Education	8	18.1	20.1	No
	Miles	8	10.1	20.1	No
2	Sex	4	5.05	13.3	No
	Age	8	13.3	20.1	No
	Education	10	8.69	23.2	No
	Miles	8	3.71	20.1	No
3	Sex	2	1.47	9.21	No
	Age	6	3.51	16.8	No
	Education	6	2.73	16.8	No
	Miles	4	2.87	13.3	No
4	Sex	2	1.16	9.21	No
	Age	6	11.9	16.8	No
	Education	6	14.3	16.8	No
	Miles	4	11.8	13.3	No
5	Sex	4	4.31	13.3	No
	Age	10	13.9	23.2	No
	Education	10	22.1	23.2	No
	Miles	10	7.54	23.2	No

1 = RR Xing/Stop Ahead

2 = RXR Tracks Blocked

3 = RXR Tracks Blocked/Stop Ahead

4 = RXR Crossing Blocked/Stop Ahead

5 = Railroad Crossing/Tracks Blocked

Null Hypothesis: The distribution of responses is independent of the subgroup.

A Relative Scaling for Alternative Displays When No Hazard Exists

Five display alternatives were also selected for evaluation when no train was present and no imminent hazard existed. The alternatives are shown in Figure 20. One display was a "no information" alternative. That is, the sign was completely blank. Another alternative was only the identification of the hazard with no other information given. The remaining three alternatives gave positive information that no hazard exists.

The paired comparison technique was used to evaluate the relative acceptability of the five alternative displays. The results for the 259 respondents are shown in Figure 21. The most preferred display with a relative scale value of 1.78 was "RXR CROSSING CLEAR." A close second with a relative scale value of 1.73 was the display "RXR TRACKS CLEAR." These two displays parallel the most preferred alternatives for the condition when a train constitutes a hazard.

In third place was the display "RAILROAD CROSSING/TRACKS CLEAR" with a relative scale value of 0.86. This alternative is only half as desirable as the top rated alternatives. This again tends to indicate the preference for the standard symbol over the word message. The fourth rated display only contained the advance warning symbol "RXR," and had a relative rating of 0.80. The least desirable alternative was no information of any kind. The relative scale value was 0.0. This indicates that drivers do wish to be told when no hazard exists.

The validity of the results was checked by plotting the observed proportions (P'_{ij}) versus the calculated proportions (P''_{ij}) based on the paired comparison model. The graph shown in Figure 22

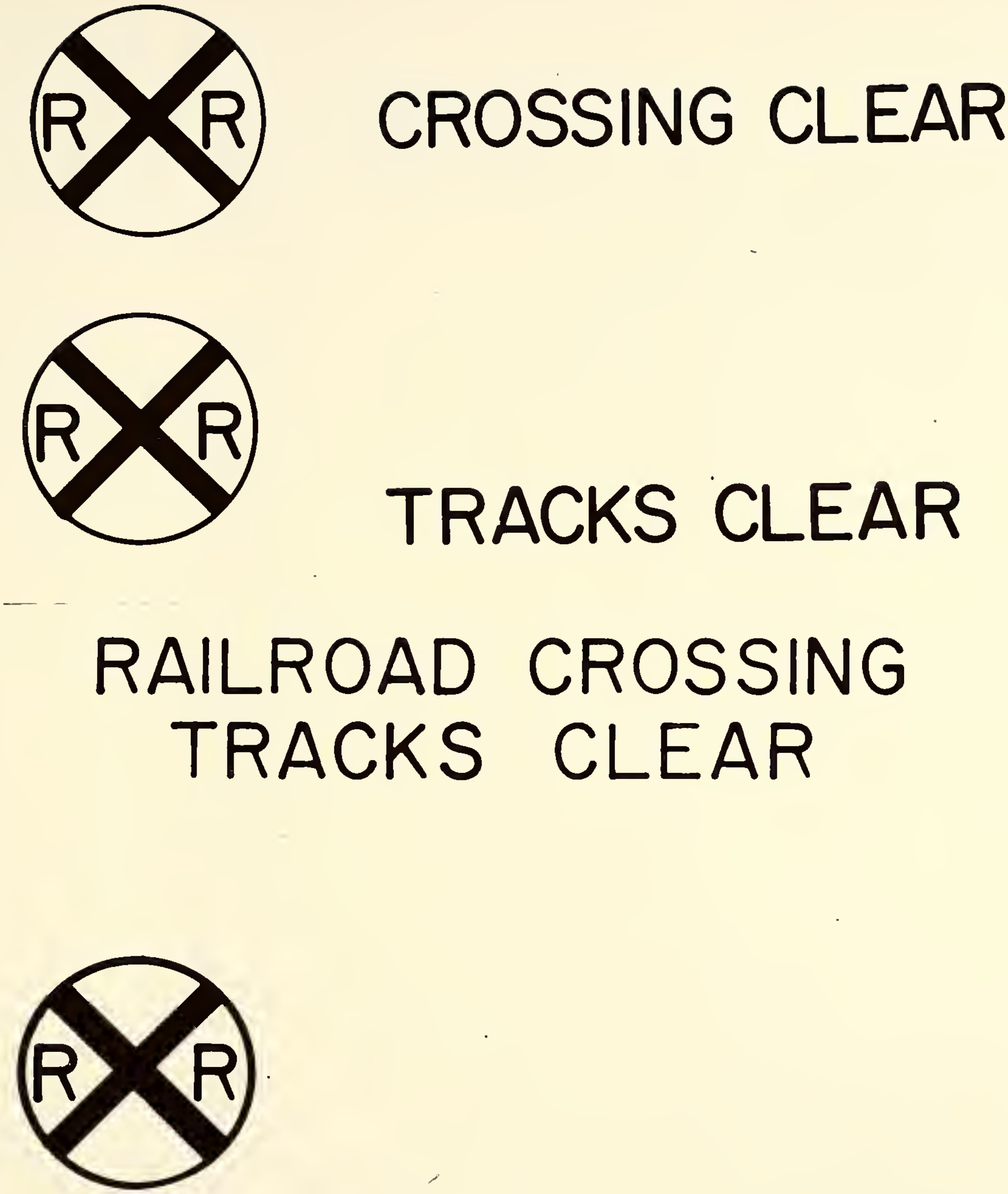


FIGURE 20. DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

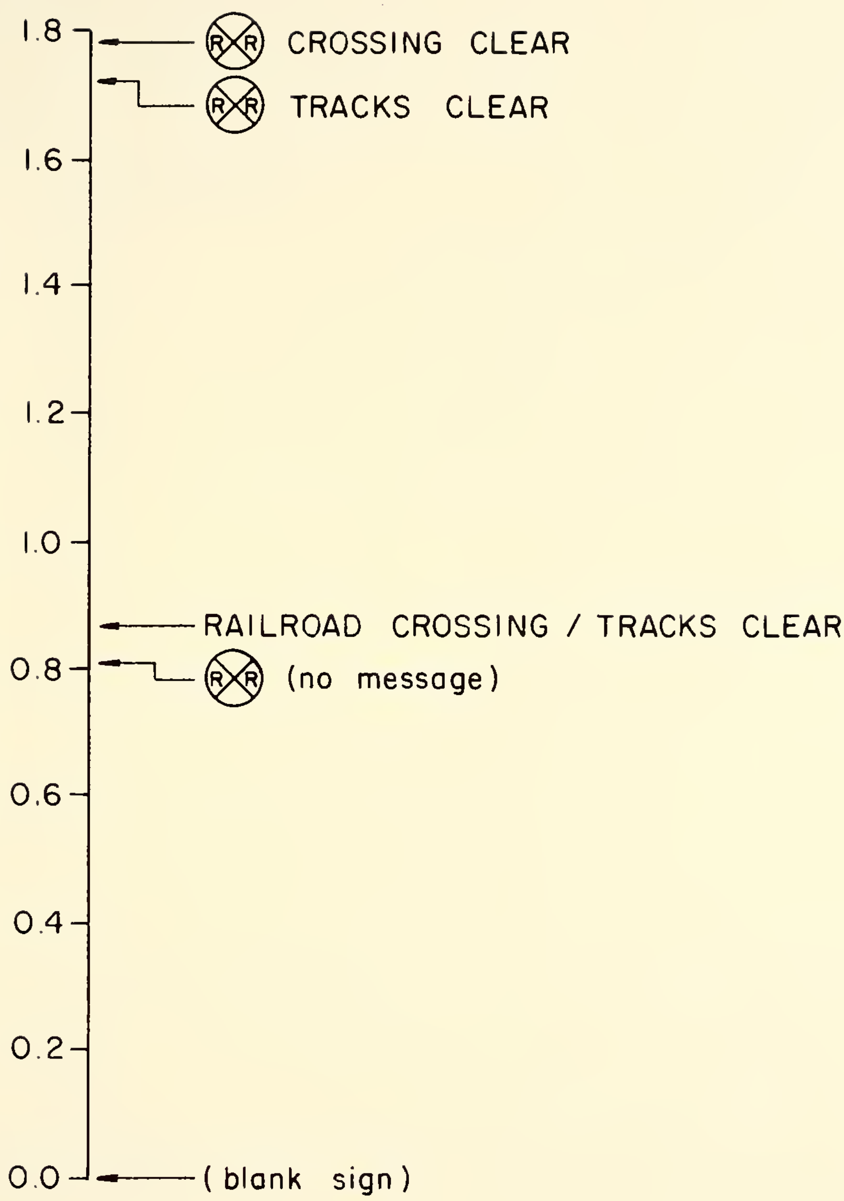


FIGURE 21. A RELATIVE SCALING FOR ALTERNATIVE DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

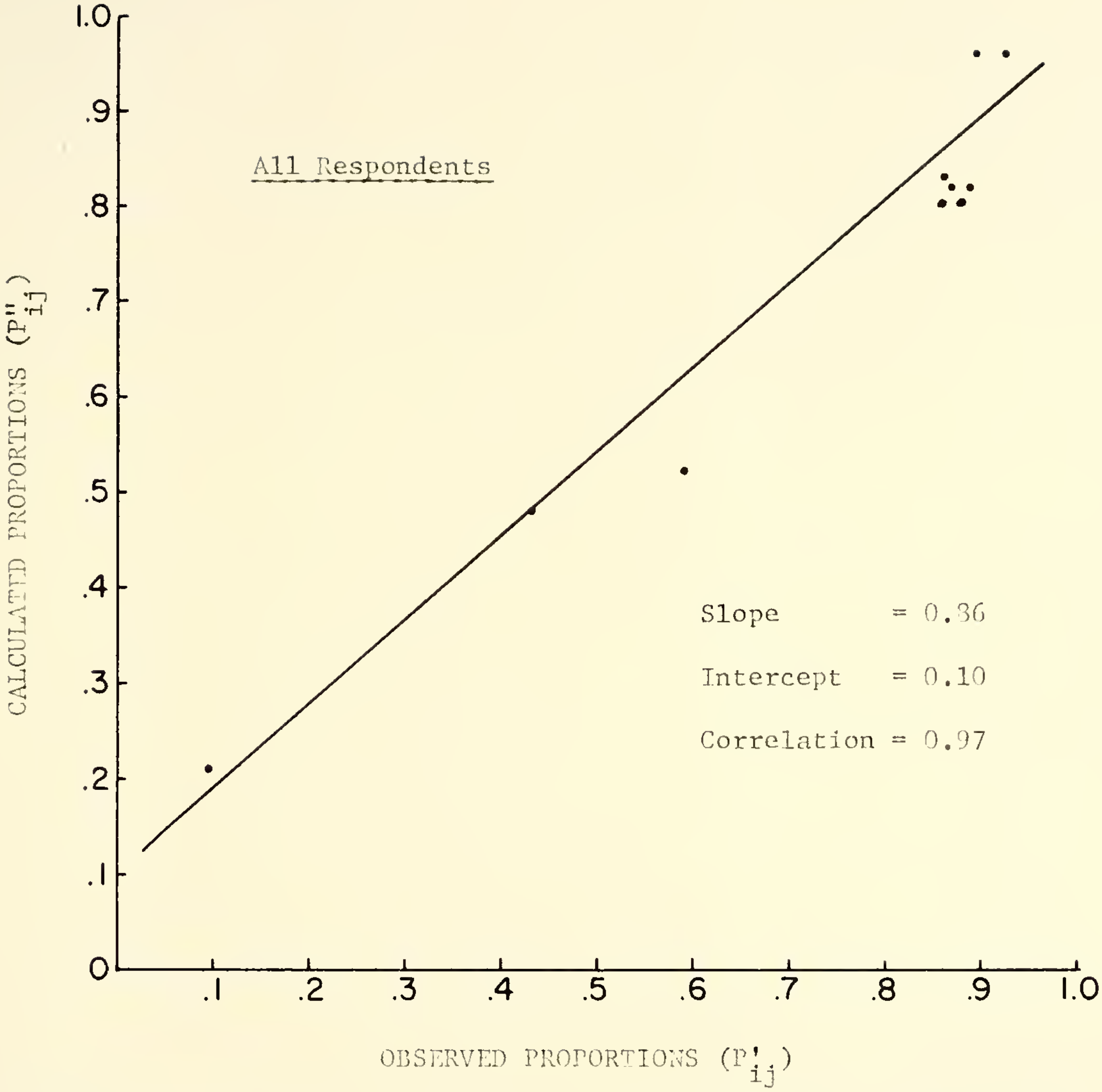


FIGURE 22. CALCULATED VERSUS OBSERVED PROPORTIONS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

indicates a reasonable fit of the data. A least squares fit was also made of the P'_{ij} versus P''_{ij} data. The results were an intercept of 0.10, a slope of 0.86, and a correlation of 0.97. The results for a perfect fit would be 0.00, 1.00, and 1.00 respectively. The results are reasonable, but not as good as some of the other models previously discussed. The difficulty in obtaining a good fit is caused by most proportions being at extreme values. That is, some alternatives were highly preferred and some were highly not preferred. However, the relative positions on the scale are reasonable ones.

A Relative Scaling by Subgroups for Displays When No Hazard Exists

The alternative displays for the no hazard condition were also analyzed to see if any subgroups had different preferences. The results of all the subgroups are in general agreement, as shown in Figure 23, except for four minor exceptions. Those respondents age 20 to 29 and those who drive 7,500 to 12,500 miles preferred the "RXR TRACKS CLEAR" display over the "RXR CROSSING CLEAR" display. The results are opposite those for all other groups, but the actual scale separation in all cases is very small. The third and fourth differences concern the same two subgroups. The third and fourth preference of the 259 respondents is switched by these two subgroups. In all cases, the main concern is with the most preferred display, therefore reducing the importance of some of the scalings.

The P'_{ij} versus P''_{ij} matrix was plotted for all subgroups. These plots are not included since a least squares fit of the data indicates the same results. As shown in Table 17, the least squares fit

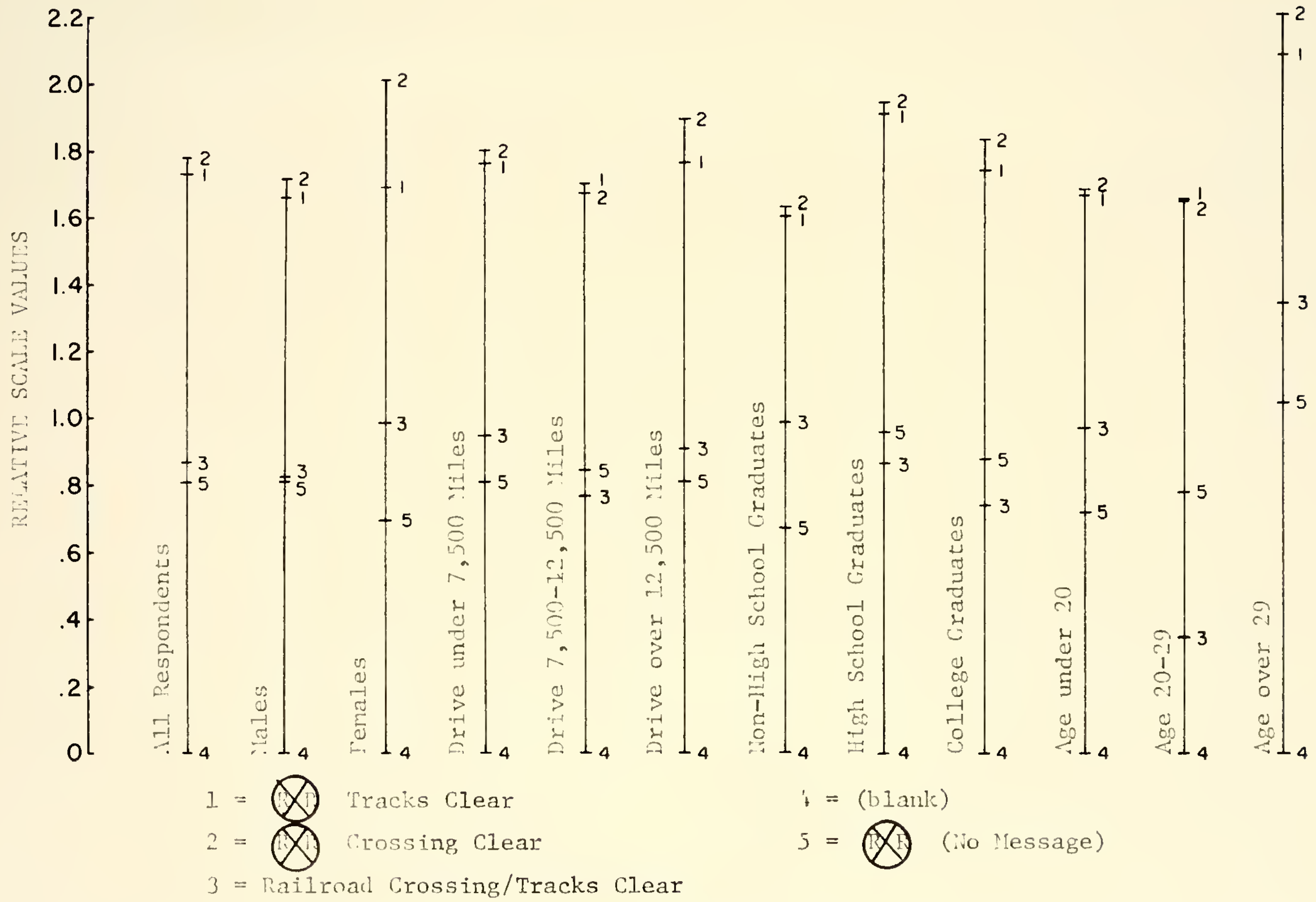


FIGURE 23. RELATIVE SCALES BY SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

TABLE 17. LEAST SQUARES FIT OF P'_{ij} VERSUS P''_{ij} BY CATEGORIES OF SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Categories of Subgroups	Intercept	Slope	Correlation
All Respondents	.0974	.8565	.9745
Males	.1068	.8427	.9667
Females	.0557	.8802	.9697
Age <20	.1087	.8465	.9753
Age 20-29	.0745	.8806	.9724
Age >29	.1157	.8320	.9661
Non-High School Graduates	.1130	.8398	.9691
High School Graduates	.0576	.8979	.9745
College Graduates	.1048	.8498	.9730
<7500 Miles	.1044	.8512	.9742
7500-12500 Miles	.0632	.8945	.9385
>12500 Miles	.0833	.8790	.9899

indicates a reasonable, although not exceptionally good, fit of the observed data by the paired comparison models.

An Absolute Scaling for Alternative Displays When No Hazard Exists

Although the method of paired comparisons provided a relative scale of acceptability, the results did not indicate the degree of acceptability of the displays. A rating scale was, therefore, used to determine an absolute scale for the five alternative displays for the "no hazard" condition. The technique was the same as for the "hazard present" condition.

The results are shown in Table 18. The "RXR CROSSING CLEAR" display was considered very acceptable with an average rating of 5.82 and a standard deviation of 1.17. Thirty-four percent of the 259 respondents indicated the maximum rating of seven, and 86 percent gave a rating greater than four. Also rated very acceptable with a mean of 5.68 and a standard deviation of 1.20 was the display "RXR TRACKS CLEAR." Thirty-one percent indicated a rating of seven and 81 percent gave a rating above four.

The display "RAILROAD CROSSING/TRACKS CLEAR" received a rating of 4.13 and had a standard deviation of 1.59. Only six percent more of the respondents rated the display above four than did those who rated it below four. At best the display is slightly acceptable.

The remaining two displays were rated undesirable. The symbol (RXR) only display had a mean of 3.53 and a standard deviation of 1.64. Fifty-one percent of the respondents rated it less than four on the scale. The "no information" (blank) sign had a mean of 1.75 and a

TABLE 18. THE MEAN, STANDARD DEVIATION, AND DISTRIBUTION OF RESPONSES FOR ALTERNATIVE DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

DISPLAY	No Response	SCALE VALUE							Mean	Standard Deviation
		1	2	3	4	5	6	7		
Number 1	2* (0.8)**	0 (0.0)	2 (0.8)	9 (3.5)	37 (14.3)	54 (20.8)	75 (29.0)	80 (30.9)	5.68	1.20
Number 2	1 (0.4)	0 (0.0)	2 (0.8)	13 (5.0)	19 (7.3)	50 (19.3)	86 (33.2)	88 (34.0)	5.82	1.17
Number 3	1 (0.4)	14 (5.4)	29 (11.2)	47 (18.1)	62 (23.9)	49 (18.9)	39 (15.1)	18 (6.9)	4.13	1.59
Number 4	0 (0.0)	190 (73.4)	22 (8.5)	15 (5.8)	12 (4.6)	4 (1.5)	5 (1.9)	11 (4.2)	1.75	1.56
Number 5	1 (0.4)	27 (10.4)	49 (18.9)	58 (22.4)	58 (22.4)	33 (12.7)	16 (6.2)	17 (6.6)	3.53	1.64

1 =  Tracks Clear

2 =  Crossing Clear

3 = Railroad Crossing/Tracks Clear

4 = (blank)

5 =  (No Message)

*Top number indicates the number of responses.

**Bottom number indicates percent of 259 total respondents.

standard deviation of 1.56. Seventy-three percent of the respondents rated it as one, the lowest possible score. Only 7.7 percent of the respondents rated it above four. The respondents definitely desire information, even when no hazard exists.

An Absolute Scaling by Subgroups for Displays When No Hazard Exists

The same categories of subgroups were again used to determine if any subgroups had different feelings concerning the alternative displays when no hazard exists. The results are shown in Table 19. The displays "RXR CROSSING CLEAR" and "RXR TRACKS CLEAR" are considered very acceptable by the eleven categories of the four subgroups. In all eleven cases for each display the average rating was greater than 5.50. As can be seen the results are in general agreement for all subgroups.

A contingency test was also performed to determine if the distribution of responses were independent of the subgroup at an alpha level of .01. The hypothesis of independence was not rejected for any of the subgroups as shown in Table 20.

Summary

Alternative displays were evaluated for the situations when a hazard exists at a grade crossing as the result of the presence of a train and also when no hazard exists. The two displays, "RXR TRACKS BLOCKED/STOP AHEAD" and "RXR CROSSING BLOCKED/STOP AHEAD" were so closely rated that both alternatives are acceptable.

For the alternative situation when no hazard exists, the two displays, "RXR CROSSING CLEAR" and "RXR TRACKS CLEAR" were so

TABLE 19. ABSOLUTE SCALES BY SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

DISPLAY	SUBGROUPS AND				
	All Respon-dents (259)	Males (209)	Females (50)	Age <20 (94)	Age 20-29 (85)
1	5.68* (1.20)**	5.57 (1.23)	6.10 (0.95)	5.56 (1.22)	5.62 (1.20)
2	5.82 (1.17)	5.73 (1.21)	6.20 (0.91)	5.80 (1.06)	5.73 (1.32)
3	4.13 (1.59)	4.05 (1.62)	4.46 (1.42)	4.32 (1.64)	3.88 (1.43)
4	1.75 (1.56)	1.82 (1.65)	1.46 (1.09)	1.82 (1.80)	1.90 (1.62)
5	3.53 (1.64)	3.52 (1.69)	3.56 (1.42)	3.50 (1.73)	3.73 (1.76)

1 =  Tracks Clear

2 =  Crossing Clear

3 = Railroad Crossing/Tracks Clear

4 = (blank)

5 =  (No Message)

*Average rating.

**Standard deviation.

TABLE 19, cont.

NUMBER OF RESPONDENTS						
Age >29 (80)	Non-H.S. Grads (88)	H.S. Grads (83)	College Grads (88)	<7500 Miles (87)	7500-12500 Miles (76)	>12500 Miles (85)
5.87 (1.17)	5.51 (1.26)	5.79 (1.19)	5.74 (1.14)	5.77 (1.02)	5.59 (1.25)	5.70 (1.31)
5.94 (1.14)	5.76 (1.12)	5.77 (1.30)	5.92 (1.11)	5.80 (1.07)	5.86 (1.19)	5.73 (1.31)
4.18 (1.68)	4.42 (1.71)	3.89 (1.48)	4.07 (1.54)	4.17 (1.69)	4.37 (1.53)	3.77 (1.54)
1.51 (1.12)	1.90 (1.86)	1.57 (1.28)	1.78 (1.47)	1.68 (1.61)	1.76 (1.45)	1.69 (1.41)
3.35 (1.37)	3.54 (1.76)	3.44 (1.59)	3.60 (1.56)	3.68 (1.74)	3.43 (1.53)	3.42 (1.60)

TABLE 20. CONTINGENCY TESTS BY SUBGROUPS FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display	Subgroups	Degrees of Freedom	Chi Square Calculated	Chi Square at .01	Reject Null Hypothesis?
1	Sex	2	6.70	9.21	No
	Age	6	5.29	16.8	No
	Education	6	3.16	16.8	No
	Miles	6	7.92	9.21	No
2	Sex	2	6.02	9.21	No
	Age	6	9.35	16.8	No
	Education	6	11.5	16.8	No
	Miles	6	9.99	16.8	No
3	Sex	4	4.61	13.3	No
	Age	8	9.42	20.1	No
	Education	8	10.2	20.1	No
	Miles	8	11.6	20.1	No
4	Sex	1	.221	6.63	No
	Age	2	2.77	9.21	No
	Education	2	1.34	9.21	No
	Miles	2	2.03	9.21	No
5	Sex	3	7.96	11.3	No
	Age	6	9.23	16.8	No
	Education	8	9.39	20.1	No
	Miles	10	3.97	23.2	No

1 = 

Tracks Clear

2 = 

Crossing Clear

3 = Railroad Crossing Clear

4 = (blank)

5 = 

(No Message)

Null Hypothesis: The distribution of responses is independent of the subgroup.

closely rated that both alternatives are acceptable.

Using the results of this research, one can now design an advance warning system for highway-railway grade crossings. It has been found that a changeable message advance warning sign is a very acceptable method of providing advance warning at highway-railway grade crossings. The necessary displays have also been evaluated for the condition when a hazard exists and when no hazard exists. The next logical step is the design of an advance warning system for highway-railway grade crossings.

CHAPTER VIII. TYPICAL INSTALLATIONS OF AN ADVANCE WARNING SYSTEM FOR HIGHWAY-RAILWAY GRADE CROSSINGS

The final objective of the research was to design and cost a new advance warning system for railroad grade crossings. In order to meet these objectives, consideration was given first to the necessary equipment, sign location, letter height, and control logic. Next, two locations were selected for preliminary designs. Finally, an estimate of the cost of installation was made for two locations and an estimate was made of the possible benefits that may be derived from the new advance warning system.

Equipment

As a result of the research in Chapters VI and VII, the messages "RXR TRACKS BLOCKED/STOP AHEAD" and "RXR TRACKS CLEAR" were the messages selected to be used in the actual field installations. The first message is for the condition when a hazard exists, and the second is for the condition when no hazard exists. Both messages were rated very desirable by the 259 respondents. The messages are shown in Figure 17 and Figure 23.

Three types of signs were selected for consideration. They were blankout signs, Varicon brand signs, and matrix signs. The blankout sign allows for the alternate display of either a message or a

blank sign. However, since the research indicated that a message was needed even when no hazard existed, this type of sign was not suitable.

The National Advertising Company, a subsidiary of the Minnesota Mining and Manufacturing Company (3M), manufactures a Varicon brand traffic control and communication system. The Varicon sign is a changeable message sign which presents visual displays to the motorist. The Varicon sign can present up to eight alternative displays of words, symbols, or both. A special retro-reflective system is used to provide proper daytime backlighting from scattered skylight and an intense retro-reflective illumination at night from vehicle headlights. At present, this sign is available with a maximum message area of four feet by five feet. This message area is not adequate for the necessary messages used in this research. Until the message area is increased, the Varicon sign is not adequate for the displays used in this research.

The third alternative was a matrix sign. An example of a matrix sign is the time and temperature signs seen at many banks. This type of sign can be made to either display any message up to a given length or can be specially designed to display specific messages. An example of the use of a specialized display is the "OPEN/CLOSED" sign used to indicate the status at truck weighing stations.

The variable matrix sign was considered appropriate for use at railroad grade crossings. Two manufacturers were contacted to obtain informal price quotations. Winko-Matic Signal Company of Avon Lake, Ohio submitted prices on a sign that could display any message up to a given length. Bell and Gustus of Chicago, Illinois submitted prices on

signs specially made to display only the required messages.

The actual signs to be used would be made in two parts. The round advance warning sign would be an illuminated area that would always be the same. The remainder of the sign would be a two-line matrix area. The top line of the matrix area would display "TRACKS BLOCKED" in amber and the bottom line "STOP AHEAD" in flashing red whenever a hazard existed. Alternatively, when no hazard exists, the top line would be "TRACKS CLEAR" in amber and the bottom line would be blank.

As the result of discussions with the Indiana State Highway Commission engineers, another problem came to light after the research had begun. The problem is accidents caused by vehicles required by law to stop at all grade crossings even when automatic protection indicates that no hazard exists. It was considered desirable at some crossings to provide a warning to drivers that a vehicle was stopped. Therefore, a third alternative message, denoted as Option #2, was considered for use at some crossings. The first line of the third message would be "TRUCK STOPPED" in amber, and the second line would be "REDUCE SPEED" in flashing red. This message was not a result of this research, but does utilize the experience gained from the research.

Sign Location and Letter Size

The location of the sign and size of the letters was determined as follows. The sign was to be located such that 85 percent of all vehicles could come to a comfortable stop given that all perception and reaction took place prior to reaching the sign. The deceleration distance was derived based on three seconds of in-gear deceleration and a

braking deceleration rate of from 4.0 mph/sec at 30 mph to 6.0 mph/sec at 80 mph. Table 21 shows the design distance for speeds from 30 to 80 mph.

TABLE 21. DECELERATION DISTANCE REQUIRED FOR VARIOUS APPROACH SPEEDS

Approach Speed	Deceleration Distance to Stop
30	275
40	400
50	525
60	675
70	825
80	975

Another consideration is size of letters. With an overhead sign, 15 feet is a minimum clearance and 20 feet is an approximate necessary maximum height (for 16-inch letters). Using 8° as a maximum visual vertical angle, the last 200 feet of distance is basically not usable since the sign cannot be readily seen.

Assuming 70 mph as a maximum approach speed at any rural crossing, the following values are generally accepted as reasonable (1):

PIEV Time--2.5 seconds

Reading Time--2.5 seconds

Therefore, a total reaction and reading distance of 500 feet is required. The message would therefore have to be visible 200 plus 500, or a total of 700 feet. The minimum letter height is 14 inches assuming 50 feet of visibility for every inch of letter height.

For variable matrix signs, 16 inches is a practical minimum for good readability. Therefore, a 16-inch letter height would be the standard sign up to and including 70 mph approach speeds.

Control Logic

An examination will be made of the control logic presently used for automatic protection. Limitations will be shown for the commonly used simple track circuit. The rationale for a 20-second minimum warning will also be considered. Finally, the control logic for a variable message sign will also be discussed.

It could be argued that poor compliance for flashers has arisen from the large amount of warning time provided at many crossings. The detection equipment provided at many crossings only has the capability to sense the presence of a train once it enters the track circuitry. The circuit is therefore made long enough to provide 20 seconds of advance warning for the fastest train. However, if this type of circuitry is used where the speed of the fastest train is three times the slowest train (e.g., a 60 mph passenger train and a 20 mph freight), then up to 60 seconds of warning is provided. This is not an uncommon occurrence. It is easy to see how non-compliance will result with a 60-second warning. Therefore, it is recommended that detection equipment used in conjunction with variable message signs provide no more than a 50 percent increase in warning time for slow trains or an absolute maximum of 30 seconds.

It is also enlightening to examine the rationality of a constant 20-second minimum warning. Let us look at the amount of time, T, required for a vehicle to clear the crossing:

$$T = P + \frac{1}{2}\frac{u}{a} + \left(\frac{w + \ell}{v}\right)$$

where

P = perception reaction time in seconds,

v = approach speed in feet per second,

a = deceleration rate in feet per second per second,

w = width of crossing,

ℓ = length of vehicle.

Next, look at the time necessary using conservative values and a design speed of 80 mph. The time, T, is 10.8 seconds when:

P = 3.0 seconds,

v = 120 ft/sec,

a = 8.8 ft/sec/sec,

w = 60 feet, and

ℓ = 60 feet.

Looking at slow speeds, for v = 45 ft/sec (30 mph) and a comfortable rate of deceleration of 5.9 ft/sec/sec, then T = 9.4 seconds. It becomes evident that 20 seconds is more than adequate for all situations.

The next question concerns when the advance warning sign should be activated. Two reasonable alternatives exist for the time of activation. The first alternative is prior to the activation of the crossing signals and the second alternative is at the same time.

The logic for advance activation of the advance warning sign is to allow vehicles which just pass the sign at the time of activation to clear the crossing. The main drawback is that if the flashers do not come on shortly after the advance warning signs, confusion might arise

from those drivers seeing the advance notice but not the flashers.

The second alternative is to provide simultaneous activation of both sign and signals. For the driver who has passed the sign, but sees the flashers, enough time should be provided to clear the crossing.

It would appear that the second alternative, simultaneous activation, should be the method used. Again, examination of the warning time is necessary for slow moving vehicles. For a 70 mph approach speed, the sign is located 825 feet from the crossing. With 20 seconds of warning, any vehicle traveling 45 ft/sec (30 mph) would clear the crossing. This is reasonable for 70 mph approach speeds. For 30 mph approach speeds, any vehicle traveling at least 13 mph would clear the crossing.

It would appear that 20 seconds of warning be the minimum and 30 seconds the maximum. The 30-second maximum is provided for a tolerance, with 20 seconds being the recommended value.

The provision of variable message advance warning signs should only be made with detection equipment meeting the above requirement. Modernization should be made prior to installations not meeting the 20 to 30 second criteria.

Location Selection

The Indiana Highway Commission and several railroads operating in Indiana indicated five locations they felt deserved additional protection. These crossings were not the result of an extensive evaluation of crossings in Indiana. It was only desired to select one or two

crossings that justified improvement so that a preliminary design and cost estimates could be made.

The two main criteria for the selection of a suitable crossing were location and accident experience. The grade crossing protection system resulting from this research is primarily intended for high-speed rural locations. The second consideration was the accident experience at the crossings. Crossings selected would have to have a consistently poor accident record.

After collection of the necessary accident data and field visits, two locations were selected for consideration as pilot sites. The first crossing is on U.S. 20 at the Chesapeake and Ohio (C & O) Railroad crossing in Porter County. The second crossing is on U.S. 31 at the Norfolk and Western (N & W) Railroad crossing in Tipton County. The locations of both crossings are indicated on the map of Indiana shown in Figure 24. The general characteristics of the locations are summarized in Table 22.

The accident experience for the two locations is shown in Table 23. The cost of fatal and personal injury accidents were based on figures developed by Hejal (16) for rural Indiana highways. Hejal estimated the cost of fatal accidents at $18,000 and the cost of personal injury accidents at $4,300. These costs reflect hospital costs, doctor's costs, legal and court costs, and miscellaneous costs such as loss of vehicle and personal time. Voorhees (26) indicates figures of $20,000 for one death, $5,000 for one non-fatal injury accident, and $1,000 for a property damage accident. It is therefore reasonable to use the cost developed by Hejal. The cost of accidents

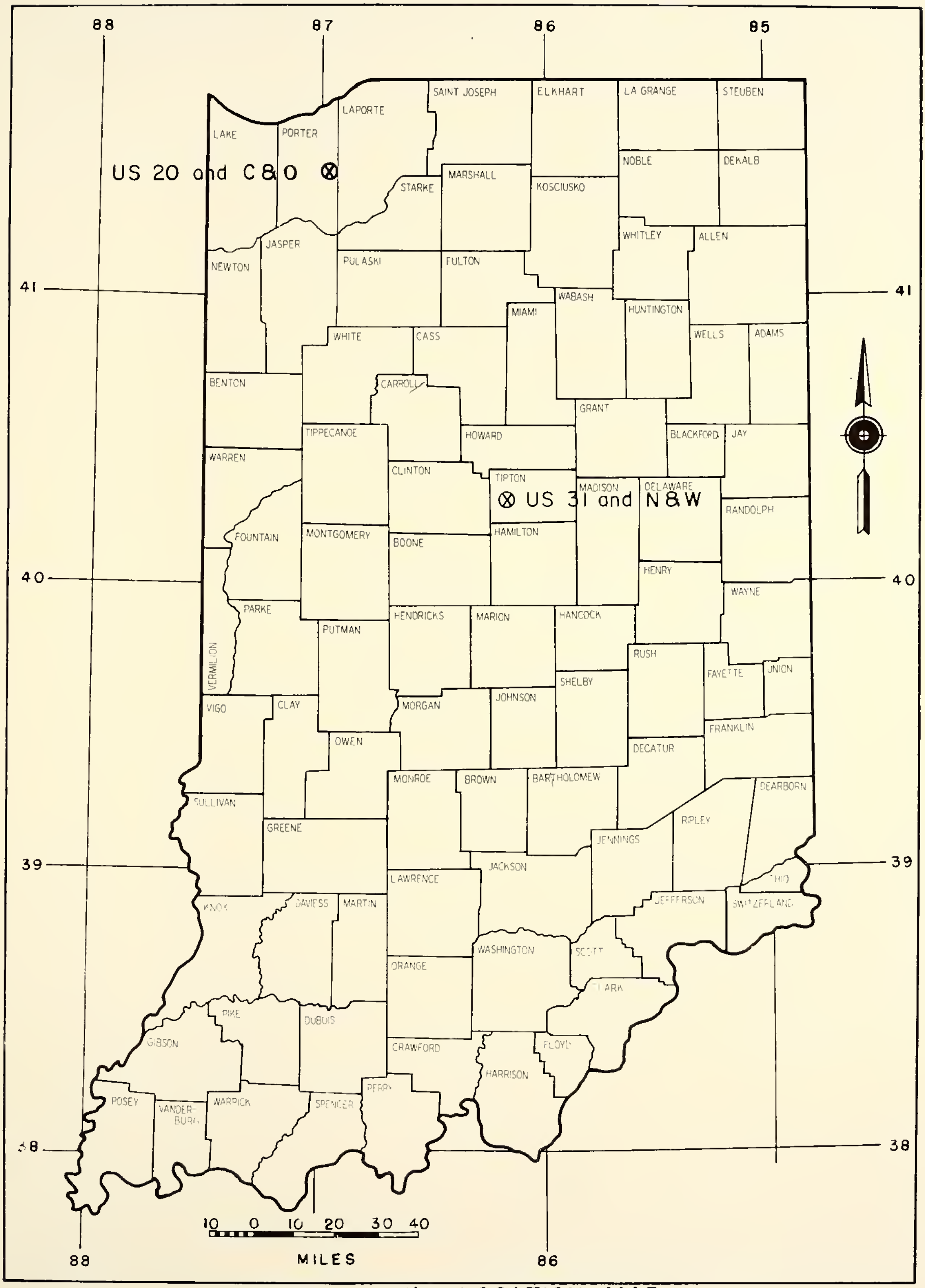


FIGURE 24. LOCATION MAP

TABLE 22. GENERAL CHARACTERISTICS OF PILOT LOCATIONS

	U.S. 20	U.S. 31
Type Facility	4-lane Undivided	4-lane Divided
Location	Rural	Rural
Lane Width	10 ft.	12 ft.
Median	None	66 ft.
Terrain	Rolling	Level
Speed Limit	55 mph	65 mph
85th Percentile Speed	55 mph	66 mph
15th Percentile Speed	40 mph	50 mph
ADT	18,000	10,000

TABLE 23. ACCIDENT EXPERIENCE AT PILOT LOCATIONS

	U.S. 20	U.S. 31
Accident Years	1966-1970	1968-1970
Fatal Accidents	0	2
Personal Injury Accidents	8	2
Property Damage Accidents	8	2
Total Property Damage	\$ 30,500	\$ 62,000
Total Accident Cost (est.)	\$ 64,900	\$107,800
Total Cost Divided by Number of Years	\$ 13,000	\$ 39,000

at both crossings are summarized in Table 23. The U.S. 20 crossing had a total cost of $64,900 over a five-year period and the U.S. 31 had a total cost of $39,000 over a three-year period.

Cost Estimates

Estimates of the costs of installing an advance warning system were made for both pilot crossings. Price estimates were obtained for both Option #1 and Option #2. Option #1 is the two message sign that was the result of the attitudinal research. Option #2 is the three message sign that includes an additional message to warn drivers of vehicles required by law to always stop. This second option was the result of consultations with the Indiana State Highway Commission.

Winko-Matic submitted a unit price of $10,850 for both the two message and three message signs. The price is a direct function of the length of the longest message since each individual matrix can display any number or letter. Bell & Gustus submitted unit costs of $3,500 for the two message option and $4,800 for the three message option. These signs were made only to display the required message, and the price is therefore a function of the number of messages displayed. The saving in the Bell & Gustus signs results from fewer lamps, simpler wiring, and simpler control logic. The Bell & Gustus signs were chosen for use because of the cost savings and a potential savings in maintenance costs due to the less complicated control logic and fewer parts.

The other fixed costs at all sites are the sign control equipment and the advance warning railroad sign to be mounted next to the variable message sign. The control equipment for the two message Option #1 was estimated at $150 per sign. For Option #2, the three

message sign, the unit cost was estimated at \$625. The added cost for Option #2 was for a presence detector and timer to activate the three message sign when a vehicle was stopped at the crossing and no other hazard existed. This estimate was based on a loop detector, although other means could be used. The round railroad signs were estimated at a unit cost of \$250.

The remainder of the costs are a function of the individual locations. These variable costs are the sign support, the length of conduit and wire, and guardrail (if required). The sign support cost is a function of the span required. The conduit and wire cost is a function of the approach speed which determines how far the sign is located from the crossing. Guardrail is required if the sign support cannot be located 30 feet or more from the traveled way.

U.S. 20 and C & O Railroad Crossing

The U.S. 20 and C & O railroad crossing was one of two selected as a pilot location. The actual geometrics of the location are shown in Figure 25. The highway is an old four-lane undivided highway with ten-foot lanes. Vision is obscured in both directions. An eastbound curve ends approximately 1,000 feet before the crossing. Westbound vision is hindered by the crest of a small hill also located about 1,000 feet from the crossing.

Improved advance warning could possibly reduce accidents at this crossing. An overhead sign located 600 feet east of the crossing would provide visibility up to the limits of the size of the message letters. A sign located 600 feet west of the crossing would provide 750 feet of visibility. Possibly a supplemental sign would be

FIGURE 25. GEOMETRICS AND ADVANCE WARNING SYSTEM LOCATION FOR U.S. 20 AND C & O RAILROAD CROSSING

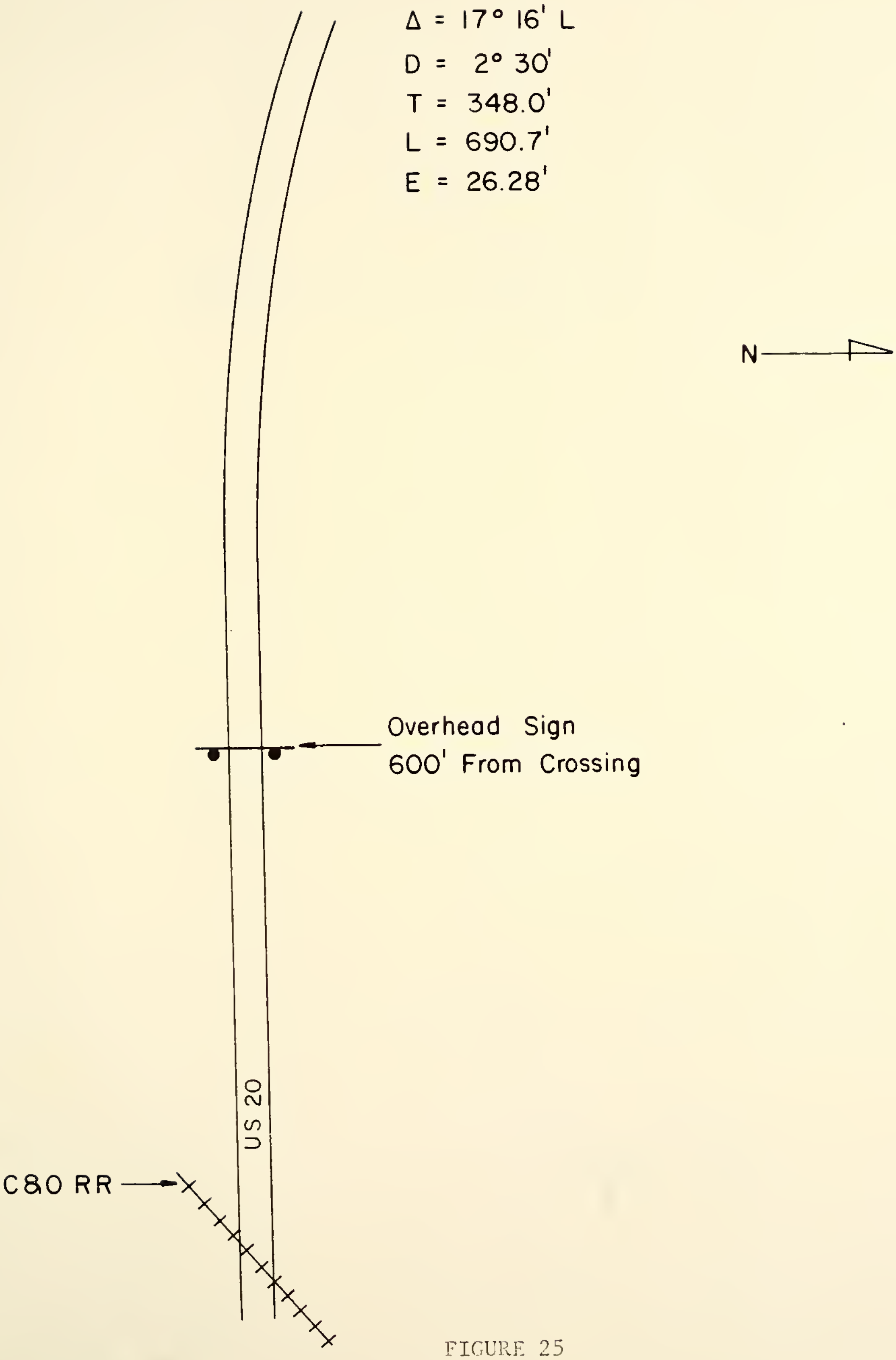

Δ = 17° 16' L
D = 2° 30'
T = 348.0'
L = 690.7'
E = 26.28'
N
Overhead Sign
600' From Crossing
US 20
C&O RR

FIGURE 25

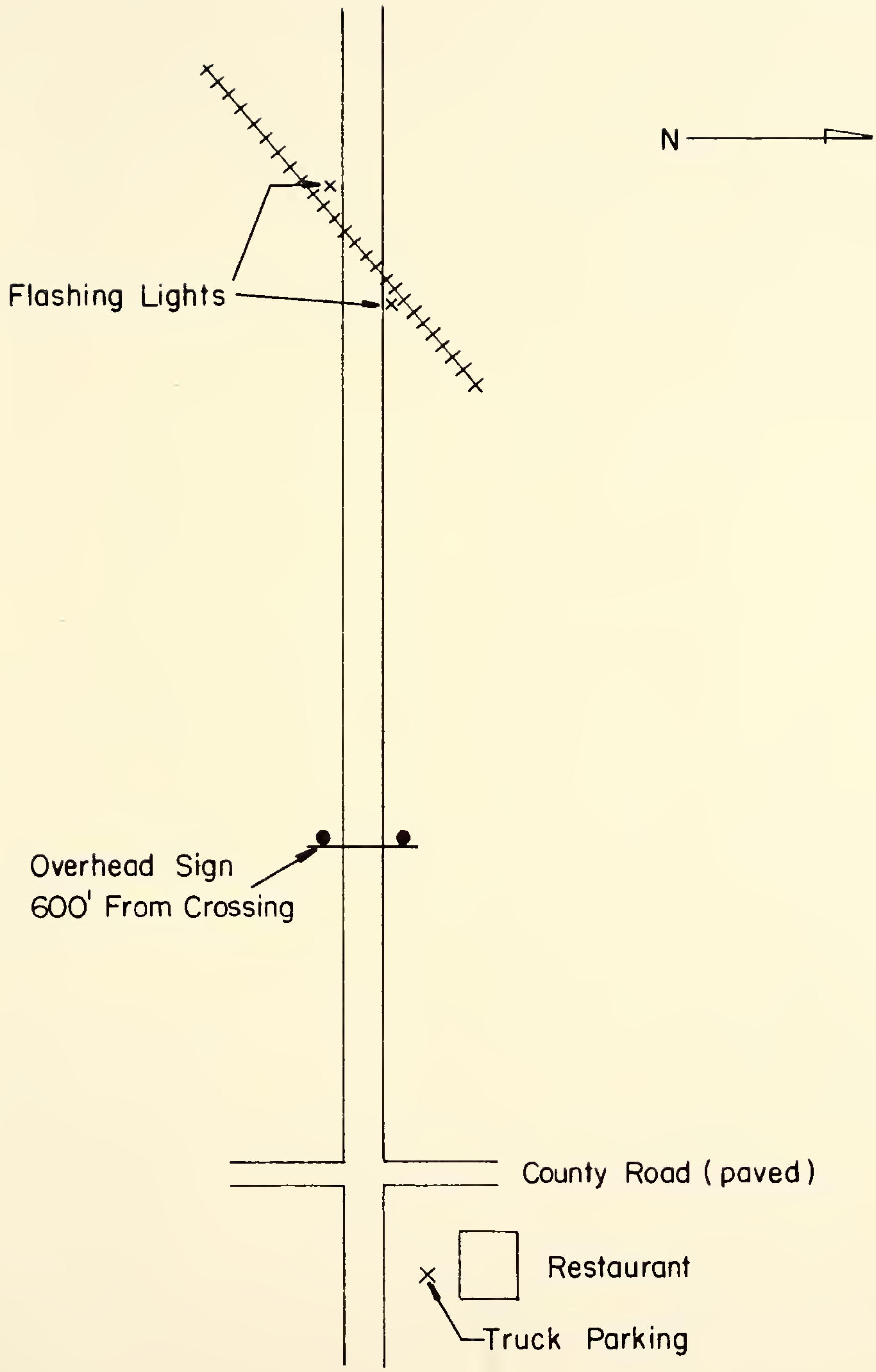


FIGURE 25, cont.

desirable to call attention to the variable message sign since visibility is less than optimum. Both sign locations were based on a 55 mph approach speed.

The total installation cost for the U.S. 20 crossing is shown in Table 24. The total cost is \$33,300 for the two message option and \$36,500 for the three message option. It was assumed that the system life was ten years with no salvage value. An interest rate of 10 percent was used. The annual equipment cost is therefore \$5,420 for Option #1 and \$5,997 for Option #2. Annual maintenance cost is estimated at \$1,000 for both options. Therefore, the total annual cost is \$6,420 for Option #1 and \$6,997 for Option #2.

U.S. 31 and N & W Railroad Crossing

The second pilot location was the N & W railroad crossing on U.S. 31 near Tipton, Indiana. The actual geometrics are shown in Figure 26. The crossing is located on a level tangent of a four-lane divided highway with 12-foot lanes. Immediately south of the crossing is the intersection of a low volume paved county road. One half mile south of the crossing is a signalized intersection.

An improved advance warning system for highway-railway grade crossings could possibly reduce accidents at this crossing which has had a bad accident record. The changeable message advance warning signs would be located 825 feet prior to the crossing for a 70 mph design speed. The signs could be located such that no guardrail would be necessary.

Table 25 shows the breakdown of the total cost of installation. The total cost for Option #1 is \$25,000 and the total cost for Option

TABLE 24. COST ESTIMATE FOR AN ADVANCE WARNING SYSTEM AT THE U.S. 20 AND C & O RAILROAD CROSSING

Item	Unit Cost	Total Cost Option #1	Total Cost Option #2
2--Two Message Signs, Option #1	$ 3,500	$ 7,000	$ --
2--Three Message Signs, Option #2	4,800	--	9,600
2--Control Cabinets, Option #1	150	300	--
2--Control Cabinets, Option #2	625	--	1,250
2--Monotube Sign Supports	3,000	6,000	6,000
Guardrail--1200 lft.	10	12,000	12,000
Conduit and Wire--1500 lft.	5	7,500	7,500
2--Railroad Signs	250	500	500
TOTAL		$33,300	$36,850
Annual Equipment Cost (10 years at 10 percent)		$ 5,420	$ 5,997
Annual Maintenance Cost		1,000	1,000
TOTAL ANNUAL COST		$ 6,420	$6,997

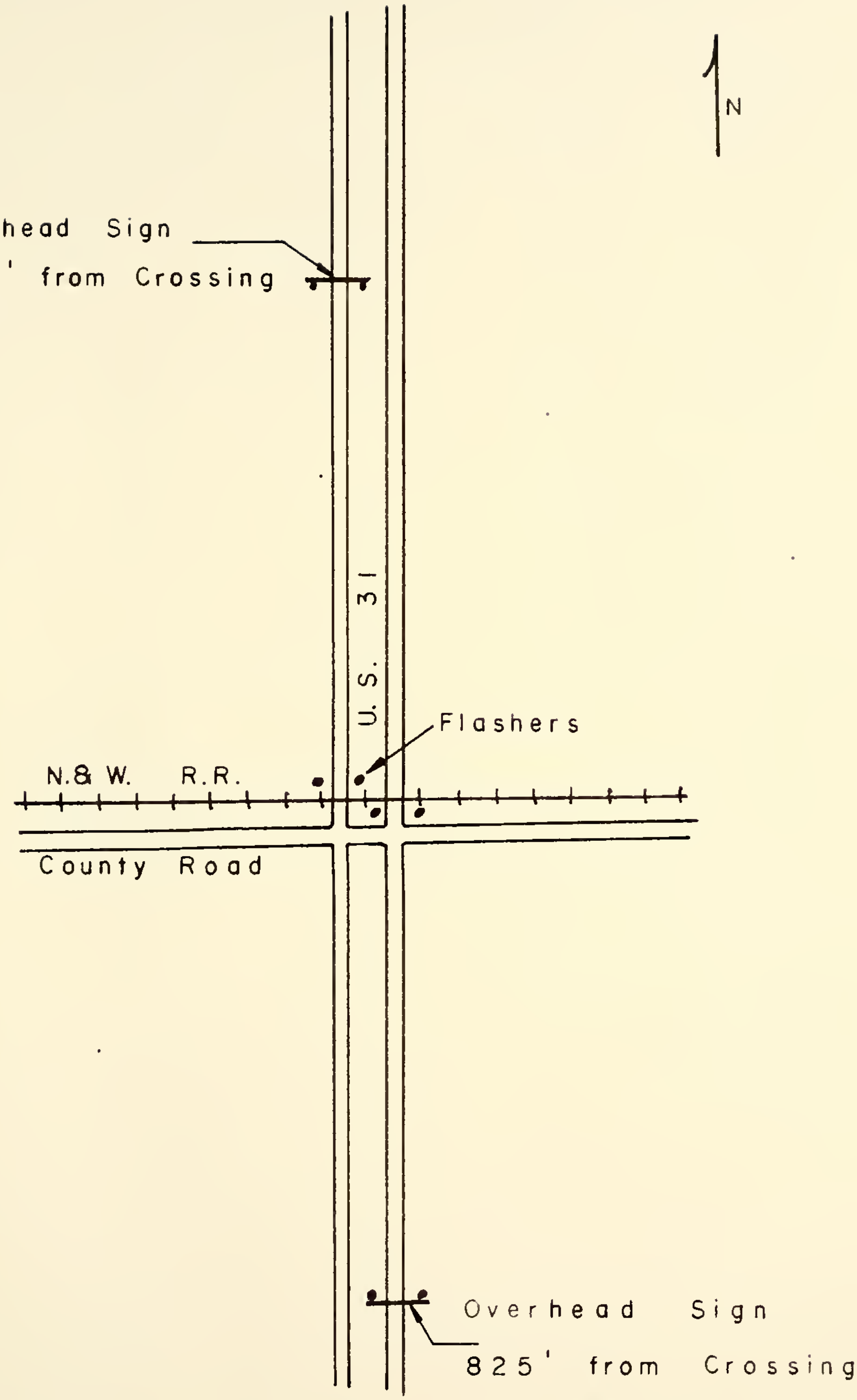


FIGURE 26. GEOMETRICS AND ADVANCE WARNING SYSTEM LOCATION FOR U.S. 31 AND N & W RAILROAD GRADE CROSSING

TABLE 25. COST ESTIMATE FOR AN ADVANCE WARNING SYSTEM AT THE U.S. 31 AND N & W RAILROAD CROSSING

Item	Unit Cost	Total Cost Option #1	Total Cost Option #2
2--Two Message Signs, Option #1	$ 3,500	$ 7,000	$ --
2--Three Message Signs, Option #2	4,800	--	9,600
2--Control Cabinets, Option #1	150	300	--
2--Control Cabinets, Option #2	625	--	1,250
2--Monotube Sign Supports	3,000	6,000	6,000
Conduit and Wire--1700 lft.	5	8,500	8,500
2--Railroad Signs	250	500	500
TOTAL		$25,000	$30,350
Annual Equipment Cost (10 years at 10 percent)		$ 4,069	$ 4,939
Annual Maintenance Cost		1,000	1,000
TOTAL ANNUAL COST		$ 5,069	$ 5,939

#2 is $30,350. Assuming a ten-year life with no salvage value, the annual equipment cost at a 10 percent interest rate is $4,069 for Option #1, and $4,939 for Option #2. Maintenance costs are estimated at $1,000 per year for both options. Therefore, the total annual cost is $5,069 for Option #1 and $5,939 for Option #2.

It can be seen that a large variation in total cost is possible. For the two pilot locations, the total cost ranged from $25,000 to nearly $37,000 for the installation. The cost will vary depending on the geometrics of the particular location.

Possible Benefits

A benefit analysis is difficult because the effectiveness of this new system is unknown. We can, however, look at the amount of accident reduction necessary to pay for the cost of the new system. That is, if a 100 percent reduction in accidents is necessary to pay for the system, it is not likely to be successful based on accident reduction.

The analysis will be based on the higher cost Option #2. It was shown that the average accident costs for a five-year period at the U.S. 20 location was nearly $13,000 per year. The annual total cost of the new advance warning system (Option #2) is nearly $7,000. Therefore, a 54 percent reduction in accidents would produce a benefit/cost ratio of one. An installation at this location would appear reasonable to evaluate the effectiveness of the system.

The U.S. 31 location had an annual average accident cost of $39,000 for a three-year period. The annual total cost of the new advance warning system installation (Option #2) would be nearly $6,000.

Therefore, a 15 percent accident reduction would result in a benefit/cost ratio of one. This location also appears to warrant a pilot project to evaluate the effectiveness of the proposed warning system.

The purpose of this simplified analysis was only to show that possible benefits could exceed the cost of the installations. This was shown to be the case at both locations. It is also believed that other locations in Indiana would justify improvement based on the cost of accidents.

Summary

An examination was made of the necessary equipment to present the alternative displays to the drivers for the advance warning system. A variable matrix sign was selected as being suitable for this project. The location of the sign was determined as a function of approach speed. Sixteen-inch letters were selected as suitable up to 70 mph approach speeds. An examination of the twenty-second warning time showed that it was more than adequate at all speeds up to 80 mph. Two locations were selected as pilot projects based on accident experience. An evaluation of the annual costs of the system indicated that it would be desirable to test the new system at the two pilot locations.

CHAPTER IX. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It has been shown that railroad grade crossings are considered by the respondents to be more hazardous than signalized intersections, yield controlled intersections, crossroads, and curves. However, the respondents consider only four of the six highway situations to be even moderately hazardous. An analysis using four subgroups resulted in the same conclusions as were made for the 259 respondents.

The improvement of the safety at railroad grade crossings was considered very important by the 259 respondents. The respondents also considered it important that highway taxes be spent on the improvement of road surfaces, and the improvement of the maintenance of painted lines. A moderately important priority was given to the improvement of directional signs and the provision of emergency telephones. The installation of more traffic signals was rated indifferent. The improvement of roadside rest areas and the mowing of grass along the sides of highways were both rated as relatively unimportant.

The overhead changeable message sign was the most preferred advance warning system by all 259 respondents. It was also considered to be very desirable by all the subgroups. In-car devices were rated lower than present flashers. The least preferred method of warning is a passive sign that indicates the same warning at all times.

Alternative displays were evaluated for the situations when a hazard exists at a grade crossing as the result of the presence of a train and also when no hazard exists. The two messages, "RXR TRACKS BLOCKED/STOP AHEAD" and "RXR CROSSING BLOCKED/STOP AHEAD" were so closely rated that both alternatives are acceptable.

For the alternative situation when no hazard exists, the two messages, "RXR CROSSING CLEAR" and "RXR TRACKS CLEAR" were so closely rated that both alternatives are acceptable.

An examination was made of the necessary equipment to present the alternative displays to the drivers. A variable matrix sign was selected as being suitable for this project. The location of the sign was determined as a function of approach speed. Sixteen-inch letters were selected as suitable up to 70 mph approach speeds. An examination of the twenty-second warning time showed that it was more than adequate at all speeds up to 80 mph. Two locations were selected as pilot projects based on accident experience. An evaluation of the annual costs of the system indicated that it would be desirable to test the new system at the two pilot locations.

Recommendations for Further Research

Three recommendations for further research are made as the result of this research:

1. Identify those railroad grade crossings with automatic protection that still have high accident rates.

2. Implement advance warning systems as designed in this research at several crossings identified in recommendation one.

3. Evaluate all aspects of the field installations resulting from recommendation two.

The crossings should be selected from the nearly 200 railroad crossings on the Indiana State Highway System having an index of more than 50,000 based on the product of the number of trains and motor vehicles per day. The crossings, in order of decreasing index, would be evaluated based on general feasibility and accident experience. An economic analysis should be run based on the previous five years' accident experience. The results of this research would be the identification of crossings requiring additional protection.

Two crossings have already been identified for immediate improvement as the result of this research. Several other installations should also be made in order to properly evaluate the effects of the proposed advance warning system. The evaluation should include all aspects of this research. The basic equipment and alternative detection equipment must be evaluated. The theoretical basis for the location of the sign must be confirmed or revised. Actual driver response to these signs should be evaluated to see if the sign is as effective as the attitudinal research indicates. The final result would hopefully be an effective system to reduce accidents at many highway-railway grade crossings.

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APPENDICES

APPENDIX A. QUESTIONNAIRE

APPENDIX B. PSYCHOLOGICAL SCALING METHODS

APPENDIX B. PSYCHOLOGICAL SCALING METHODS

Psychological scaling methods are procedures for constructing scales for the measurement of psychological attributes. Scaling methods can be used for the measurement of psychological attributes of stimuli which have no measurable physical value.

The Method of Paired Comparisons

The method of paired comparisons is based on Thurstone's (25) Law of Comparative Judgement. The Law of Comparative Judgement relates the proportion of times any stimulus j is judged greater than any other stimulus k to the scale values and discriminal dispersions of the two stimuli. The relationships developed in the Law of Comparative Judgement are based on the following postulates:

1. Each stimulus when presented to an observer results in a discriminal process which has some value on the psychological continuum of interest.

2. As the result of momentary fluctuations in the respondent, a given stimulus does not always excite the same discriminal process, but may excite one with a higher or lower value. Each stimulus thus has associated with it a normal distribution of discriminal processes.

3. The mean and standard deviation of the distribution associated with a stimulus are taken as its scale value and discriminal dispersion respectively.

Figure B2 shows the theoretical distributions for two stimuli j and k. Let S_j and S_k correspond to the scale values of two stimuli and σ_j and σ_k to their discriminal dispersions.

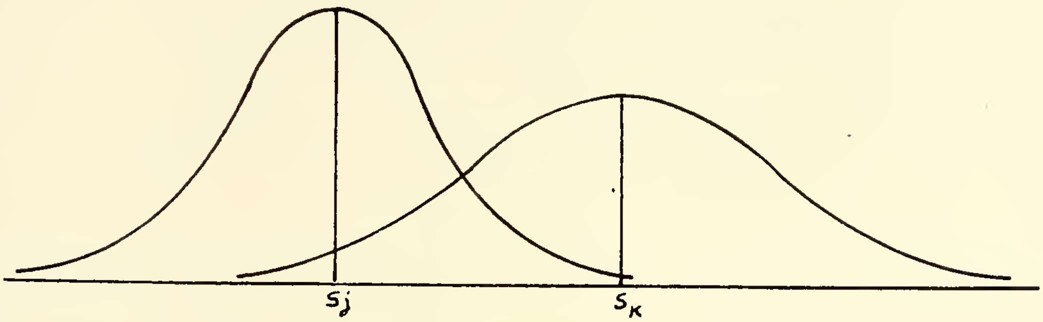

FIGURE B1. THEORETICAL DISTRIBUTIONS FOR TWO STIMULI j AND k

For each pair of stimuli presented to a respondent, the result is two discriminal processes: d_j and d_k. For the given pair, the difference in discriminal processes $(d_k - d_j)$ is called a discriminal difference. Given a large number of observations, the distribution of differences would themselves be normally distributed on the psychological continuum. Furthermore, the mean of this distribution is the difference in scale values since the difference between means is equal to the mean of differences. Similarly, the standard deviation of the differences can be shown to be

$$\sigma_{d_k - d_j} = (\sigma_j{}^2 + \sigma_k{}^2 - 2r_{jk}\sigma_j\sigma_k)^{\frac{1}{2}} \qquad \text{(B1)}$$

where r_{jk} is the correlation between discriminal processes.

Figure B2 illustrates the distribution of discriminal differences.

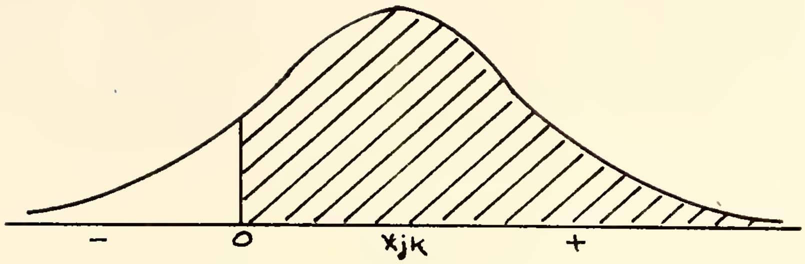

FIGURE B2. THE DISTRIBUTION OF DISCRIMINAL DIFFERENCES

The shaded portion indicates the portion of times $(d_k - d_j)$ is positive or the proportion of times stimulus k is judged greater than stimulus j. On the other hand, the unshaded portion to the left of zero indicates the portion of times $(d_k - d_j)$ is negative. The mean of the distribution is equal to the difference in scale values $(s_k - s_j)$. Thus, from the theoretical proportion of times stimulus k is judged greater than stimulus j one can determine the difference $(s_k - s_j)$ from a table of values of the standard normal distribution. The difference is called X_{jk} and is measured in $\sigma_{d_k - d_j}$ units. Therefore, we can write the equation:

$$S_k - S_j = X_{jk}\sigma_{d_j - d_k} \tag{B2}$$

Combining equations (B1) and (B2) we get the complete form of the law of comparative judgement:

$$S_k - S_j = X_{jk}(\sigma_j{}^2 + \sigma_k{}^2 - 2r_{jk}\sigma_j\sigma_k)^{\frac{1}{2}} \tag{B3}$$

Unfortunately, there is no solution in this form because there are always more variables than equations regardless of the number of

stimuli. Thurstone (25) illustrated a number of simplifying assumptions that can be made. We will only be concerned with his Case V. Case V makes the assumption that the dispersions are equal ($\sigma_j = \sigma_k = \sigma$) and also assumes zero correlation. With the above two assumptions, equation (B3) reduces to:

$$S_k - S_j = cX_{jk} \tag{B4}$$

Separate equations can then be written for each of the n stimuli.

It has been shown by Mosteller (21) that there is a least squares solution to the n resulting equations. Then using the observed P'_{jk} data, one can calculate an X'_{jk} as an estimate of X_{jk}. The solution to the set of equations can be shown to yield

$$S'_k = \frac{1}{n} \sum_{j=1}^{n} X'_{jk} \quad (k = 1,2,\ldots,n) \tag{B5}$$

Thus, a least squares estimate of the scale values can be obtained simply by averaging the columns of X' matrix.

It should be noted that all cells in the X' matrix must be filled. Also, if any observed proportions P'_{jk} are 0.00, or 1.00, the transformation to X'_{jk} cannot be made.

Rating Scale Technique

There are numerous variations of the rating scale technique. Variations include the number of scale divisions or categories used, the number of descriptors used, and the method of evaluation. Generally, it is recommended that between five and ten divisions be used, depending upon the particular application. Seven divisions were used in this study. Some prefer to use descriptors to indicate the

relative positions on the scale while others use numbers. In this study, seven numbers were used with the pertinent descriptors at each end of the scale. The use of numbers implies equal intervals more easily than does the use of descriptive categories.

Complicated analysis using the law of categorical judgement can be used in the analysis. The use of numbered scales implying equal intervals, however, allows simple analysis using mean values. A check of the distribution of responses should be made to see that the distribution is not bimodal, or even multimodal. This problem did not exist with this research data.

As a check on the results using a simple mean technique an analysis was also made using a technique based on the law of categorical judgement. The results were identical and therefore the simpler mean technique was the preferred method of analysis.

Calculations

For each paired comparison question with n stimuli, n(n-1)/2 pairs of stimuli were presented to the respondent. From the actual responses, a P'_{ij} matrix is constructed for each question where the ith column and jth row represent the proportion of times the ith stimulus is preferred over the jth stimulus. Since $P'_{ij} + P'_{ji} = 1$, P'_{ji} is calculated by simple subtraction. Tables B1, B2, B3, and B4 are the P'_{ij} matrix for the hazard evaluation, method of warning, message preference--train present, and message preference--no train, respectively.

From the P'_{ij} matrix, the X'_{ij} matrix is calculated using a table of normal deviates, as shown in Tables B5, B6, B7, and B8. Summing and

averaging the columns results in a least squares solution of the scale values. Since no inherent zero point exists, the lowest value is subtracted from all values, resulting in a scale with zero as the lowest value. Using the average scale values calculated, it is possible to recalculate the proportions necessary to produce the average scale values. The calculated proportion matrices shown in Tables B9, B10, B11, and B12 are used to determine the adequacy of the model. If the model is a good fit, a high linear correlation will exist between the P'_{ij} (observed) and P''_{ij} (calculated) matrix.

TABLE B1. OBSERVED PROPORTIONS (P'_{ij}) FOR THE SIX HIGHWAY HAZARDS

Hazard in column i judged greater than row j

j \ i	1	2	3	4	5	6
1	.5000	.6667	.6770	.6357	.4457	.6977
2	.3333	.5000	.6094	.6085	.3953	.6279
3	.3230	.3906	.5000	.4690	.2558	.4341
4	.3643	.3915	.5310	.5000	.3217	.5969
5	.5543	.6047	.7442	.6783	.5000	.6512
6	.3023	.3721	.5659	.4031	.3488	.5000

Hazards

1. Signal Ahead
2. Stop Ahead
3. Railroad Crossing
4. Yield Ahead
5. Curve
6. Crossroad

TABLE B2. OBSERVED PROPORTIONS (P'_{ij}) FOR WARNING SYSTEMS

System in column i judged greater than row j

j \ i	1	2	3	4	5
1	.5000	.1667	.2239	.2857	.1274
2	.8333	.5000	.5039	.6641	.3050
3	.7761	.4961	.5000	.6564	.2597
4	.7143	.3359	.3436	.5000	.1124
5	.8726	.6950	.7403	.8876	.5000

Warning System

1. Changeable message sign
2. In-car visual message
3. In-car audio message
4. Standard flashing lights
5. Passive warning sign

TABLE B3. OBSERVED PROPORTIONS (P'_{ij}) FOR DISPLAYS FOR ADVANCE WARNING SYSTEM WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display in column i judged greater than row j

				i		
		1	2	3	4	5
	1	.5000	.6938	.8764	.8842	.6240
	2	.3062	.5000	.8996	.8533	.3127
j	3	.1236	.1004	.5000	.4015	.1351
		.1158	.1467	.5985	.5000	.1236
		.3760	.6873	.8649	.8764	.5000

Display

1. RR Xing/STOP AHEAD
2. RXR TRACKS BLOCKED
3. RXR TRACKS BLOCKED/STOP AHEAD
4. RXR CROSSING BLOCKED/STOP AHEAD
5. RAILROAD CROSSING/TRACKS BLOCKED

TABLE B4. OBSERVED PROPORTIONS (P'_{ij}) FOR DISPLAYS FOR ADVANCE WARNING SYSTEM WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display in column i judged greater than row j

				i		
		1	2	3	4	5
	1	.5000	.5681	.1429	.0734	.1313
	2	.4319	.5000	.1158	.1047	.1390
j	3	.8571	.8842	.5000	.1206	.4070
	4	.9266	.8953	.8794	.5000	.9031
	5	.8687	.8610	.5930	.0969	.5000

Display

1.  TRACKS CLEAR
2.  CROSSING CLEAR
3. RAILROAD CROSSING/TRACKS CLEAR
4. (blank sign)
5.  (no message)

TABLE B5. SCALE CALCULATIONS FOR THE SIX HIGHWAY HAZARDS

Normal Deviate Matrix--Scale separations between pairs

j \ i	1	2	3	4	5	6
1	0.0000	.4307	.4594	.3469	-.1364	.5177
2	-.4307	0.0000	.2777	.2755	-.2654	.3263
3	-.4594	-.2777	0.0000	-.0778	-.6563	-.1659
4	-.3469	-.2755	.0778	0.0000	-.4629	.2453
5	.1364	.2654	.6563	.4629	0.0000	.3885
6	-.5177	-.3263	.1659	-.2453	-.3885	0.0000

Column Mean

-.2697	-.0306	.2729	.1270	-.3183	.2187

Scale with Zero Assumed = Lowest Value

.0485	.2877	.5911	.4453	0.0000	.5369

Hazards

1. Signal Ahead
2. Stop Ahead
3. Railroad Crossing
4. Yield Ahead
5. Curve
6. Crossroad

TABLE B6. SCALE CALCULATIONS FOR WARNING SYSTEMS

Normal Deviate Matrix--Scale separations between pairs

j \ i	1	2	3	4	5
1	0.0000	-.9674	-.7590	-.5659	-1.1387
2	.9674	0.0000	.0099	.4237	-.5100
3	.7590	-.0099	0.0000	.4026	-.6443
4	.5659	-.4237	-.4026	0.0000	-1.2138
5	1.1387	.5100	.6443	1.2138	0.0000

Column Mean

.6862	-.1782	-.1015	.2948	-.7014

Scale with Zero Assumed = Lowest Value

1.3876	.5232	.5999	.9962	0.0000

Warning System

1. Changeable message sign
2. In-car visual message
3. In-car audio message
4. Standard flashing lights
5. Passive warning sign

TABLE B7. SCALE CALCULATIONS FOR DISPLAYS FOR ADVANCE WARNING SYSTEM WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Normal Deviate Matrix--Scale separations between pairs

j \ i	1	2	3	4	5
1	0.0000	.5066	1.1574	1.1961	.3161
2	-.5066	0.0000	1.2794	1.0506	-.4881
3	-1.1574	-1.2794	0.0000	-.2493	-1.1024
4	-1.1961	-1.0506	.2493	0.0000	-1.1574
5	-.3161	.4881	1.1024	1.1574	0.0000

Column Mean

-.6352	-.2670	.7577	.6310	-.4864

Scale with Zero Assumed = Lowest Value

0.0000	.3682	1.3930	1.2662	.1489

Display

1. RR Xing/STOP AHEAD
2.  TRACKS BLOCKED
3.  TRACKS BLOCKED/STOP AHEAD
4.  CROSSING BLOCKED/STOP AHEAD
5. RAILROAD CROSSING/TRACKS BLOCKED

TABLE B8. SCALE CALCULATIONS FOR DISPLAYS FOR ADVANCE WARNING SYSTEM WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Normal Deviate Matrix--Scale separations between pairs

j \ i	1	2	3	4	5
1	0.0000	.1715	-1.0676	-1.4512	-1.1204
2	-.1715	0.0000	-1.1961	-1.2555	-1.0848
3	1.0676	1.1961	0.0000	-1.1719	-.2353
4	1.4512	1.2555	1.1719	0.0000	1.2994
5	1.1204	1.0848	.2353	-1.2994	0.0000

Column Mean

.6935	.7416	-.1713	-1.0356	-.2282

Scale with Zero Assumed = Lowest Value

1.7291	1.7772	.8643	0.0000	.8074

Display

1. 

TRACKS CLEAR
2. 

CROSSING CLEAR
3. RAILROAD CROSSING/TRACKS CLEAR
4. (blank sign)
5. 

(no message)

TABLE B9. CALCULATED PROPORTIONS (P''_{ij}) FOR THE SIX HIGHWAY HAZARDS

Hazard in column i judged greater than row j

j \ i	1	2	3	4	5	6
1	0.0000	.5945	.7063	.6542	.4806	.6874
2	.4055	0.0000	.6192	.5626	.3868	.5984
3	.2937	.3808	0.0000	.4420	.2772	.4784
4	.3458	.4374	.5580	0.0000	.3281	.5365
5	.5194	.6132	.7228	.6719	0.0000	.7043
6	.3126	.4016	.5216	.4635	.2957	0.0000

Hazards

1. Signal Ahead
2. Stop Ahead
3. Railroad Crossing
4. Yield Ahead
5. Curve
6. Crossroad

TABLE B10. CALCULATED PROPORTIONS (P''_{ij}) FOR WARNING SYSTEMS

System in column i judged greater than row j

j \ i	1	2	3	4	5
1	0.0000	.1937	.2154	.3478	.0826
2	.8063	0.0000	.5306	.6819	.3004
3	.7846	.4694	0.0000	.6541	.2743
4	.6522	.3181	.3459	0.0000	.1596
5	.9174	.6996	.7257	.8404	0.0000

Warning Systems

1. Changeable message sign
2. In-car visual message
3. In-car audio message
4. Standard flashing lights
5. Passive warning sign

TABLE B11. CALCULATED PROPORTIONS (P''_{ij}) FOR DISPLAYS FOR ADVANCE WARNING SYSTEM WHEN A HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display in column i judged greater than row j

j \ i	1	2	3	4	5
1	0.0000	.6436	.9182	.8973	.5592
2	.3564	0.0000	.8473	.8154	.4132
3	.0818	.1527	0.0000	.4496	.1067
4	.1027	.1846	.5504	0.0000	.1319
5	.4408	.5868	.8933	.8681	0.0000

Display

1. RR Xing/STOP AHEAD
2.  TRACKS BLOCKED
3.  TRACKS BLOCKED/STOP AHEAD
4.  CROSSING BLOCKED/STOP AHEAD
5. RAILROAD CROSSING/TRACKS BLOCKED

TABLE B12. CALCULATED PROPORTIONS (P''_{ij}) FOR DISPLAYS FOR ADVANCE WARNING SYSTEMS WHEN NO HAZARD EXISTS AT A HIGHWAY-RAILWAY GRADE CROSSING

Display in column i judged greater than row j

j \ i	1	2	3	4	5
1	0.0000	.5192	.1936	.0419	.1783
2	.4808	0.0000	.1807	.0378	.1661
3	.8064	.8193	0.0000	.1937	.4773
4	.9581	.9622	.8063	0.0000	.7903
5	.8217	.8339	.5227	.2097	0.0000

Display

1.  TRACKS CLEAR
2.  CROSSING CLEAR
3. RAILROAD CROSSING/TRACKS CLEAR
4. (blank sign)
5.  (no message)